The Cover: Much of the ICF/NIF Program's work this year has been in direct pursuit of finalizing systems or components that are part of the National Ignition Facility (NIF) design. The top left photo shows a KDP crystal grown using the rapid-growth technique that the NIF will employ. The top right photo shows an assembled prototype NIF amplifier that is 4 slabs high by 2 wide by 1 long. The bottom photo shows a prototype NIF plasma electrode Pockels cell. These technologies are discussed more fully where the photos appear in the Program Overview in this Annual Report (pages xxiii, xvii, and xix, respectively).

The **central photo** shows the status of the NIF construction effort in September 1997, which marks the end of the fiscal year reported in this Annual Report. By the end of FY 1997, an engineering and support team with almost 400 members drawn from Lawrence Livermore National Laboratory, Sandia National Laboratories, Los Alamos National Laboratory, and the University of Rochester's Laboratory for Laser Energetics was approximately halfway through Title II (final) design, with nearly 90% of all requirements and interfaces under configuration control. NIF structural design reached 100% levels in many areas, and by year's end excavation was almost complete, with concrete being poured. Five of the eight conventional facilities construction packages were awarded for site preparation, site excavation, target building mat, laser bay foundations, laser building shell, and the Optics Assembly Building. The NIF will occupy a building that is 704 feet long, 403 feet wide, and 85 feet tall, about the size of a football stadium. The NIF is twice as tall, long, and wide as LLNL's Nova laser facility.

The NIF will be a 192-beam inertial confinement fusion laser facility for demonstration of fusion ignition and modest energy gain in the laboratory. It will be used primarily for research associated with the U.S. Department of Energy's Stockpile Stewardship Program. It will also be a valuable instrument in many fields, such as astrophysics and plasma physics. In addition, the NIF will establish the scientific basis for electric power generation by inertial confinement fusion. Although the NIF will be fully operational in 2003, partial operation will begin in 2001. The third 1997 *Quarterly Report* is dedicated to the NIF Title I Design and Title II Activities; the third-quarter articles also appear on pages 95 to 222 of this *Annual Report* (minus the original foreword and preface) and is available on the World Wide Web (see "On the Web").

On the Web: The progress of the NIF construction effort is captured regularly in a photo catalogue on the Web at http://lasers.llnl.gov/lasers/nif/building. In addition, NIF construction is reported with other noteworthy topics in the ICF/NIF Program's new Monthly Highlights, which began in September of 1997. The monthly highlights, quarterly reports, and annual reports are all available on the Web at http://lasers.llnl.gov/lasers/inertial.html; the inaugural issue of the Monthly Highlights is also reprinted in this Annual Report.

Questions and comments relating to the technical content of the journal should be addressed to the ICF Program Office, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA, 94551, or to kauffman2@llnl.gov.

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1997

ICF

Annual

Report

MS Date June 1998

Lawrence Livermore National Laboratory

FOREWORD

The *ICF Annual Report* provides documentation of the achievements of the LLNL ICF Program during the fiscal year by the use of two formats: (1) an Overview that is a narrative summary of important results for the fiscal year and (2) a compilation of the articles that previously appeared in the *ICF Quarterly Report* that year. Both the Overview and *Quarterly Report* are also on the Web at http://lasers.llnl.gov/lasers/pubs/icfq.html.

Beginning in Fiscal Year 1997, the fourth quarter issue of the *ICF Quarterly* was no longer printed as a separate document but rather included in the *ICF Annual*. This change provided a more efficient process of documenting our accomplishments without unnecessary duplication of printing. In addition we introduced a new document, the *ICF Program Monthly Highlights*. Starting with the September 1997 issue and each month following, the *Monthly Highlights* will provide a brief description of noteworthy activities of interest to our DOE sponsors and our stakeholders.

The underlying theme for LLNL's ICF Program research continues to be defined within DOE's Defense Programs missions and goals. In support of these missions and goals, the ICF Program advances research and technology development in major interrelated areas that include fusion target theory and design, target fabrication, target experiments, and laser and optical science and technology.

While in pursuit of its goal of demonstrating thermonuclear fusion ignition and energy gain in the laboratory, the ICF Program provides research and development opportunities in fundamental high-energy-density physics and supports the necessary research base for the possible long-term application of inertial fusion energy for civilian power production. ICF technologies continue to have spin-off applications for additional government and industrial use. In addition to these topics, the *ICF Annual Report* covers non-ICF funded, but related, laser research and development and associated applications. We also provide a short summary of the quarterly activities within Nova laser operations, Beamlet laser operations, and National Ignition Facility laser design.

LLNL's ICF Program falls within DOE's national ICF program, which includes the Nova and Beamlet (LLNL), OMEGA (University of Rochester Laboratory for Laser Energetics), Nike (Naval Research Laboratory), and Trident (Los Alamos National Laboratory) laser facilities. The Particle Beam Fusion Accelerator (Z) and Saturn pulsed-power facilities are at Sandia National Laboratories. General Atomics, Inc., develops and provides many of the targets for the above experimental facilities. Many of the *ICF Annual Report* articles are co-authored with our colleagues from these other ICF institutions.

Questions and comments relating to the technical content of the journal should be addressed to the ICF Program Office, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94551.

Jason Carpenter Publication Editor

Don Correll Managing Editor

ACKNOWLEDGMENTS

We thank the 27 authors and their co-authors who contributed to this *Annual Report*. Their work, published in our four *Quarterly Reports*, is compiled here to highlight LLNL's ICF Program accomplishments for the year. We are grateful for their willingness to take time from busy schedules to write the articles that describe their work. We thank the four *Quarterly Report* scientific editors James Hammer, William Kruer, John Murray, and Charles Vann for their efforts and diligent review to ensure the quality of each *Quarterly Report*. We thank Roy Johnson for his careful classification reviews. We also thank the secretaries for typing manuscripts, arranging meetings, and offering other invaluable assistance.

We thank Technical Information Department (TID) editors Jason Carpenter, Cindy Cassady, Cara Corey, Robert Kirvel, Karen Lew, Al Miguel, Ann Parker, Joy Pérez, and Dabbie P. Schleich for editing and managing the production cycle; and designer Pamela Davis and artists Ken Ball, Clayton Dahlen, Galen Hazelhofer, Sandy Lynn, Mark McDaniel, and Janet Orloff for providing expertise in graphic design.

We appreciate the support of Michael Gallardo, the Government Printing Office coordinator, who worked with the Government Printing Office to obtain high-quality printing; and Mary Nijhuis of TID's Publications Services and TID's Print Plant for making sure that each publication was distributed with dispatch.

The talents and dedication of the ICF Program staff make the *ICF Annual* what it is for so many of its readers.

John Lindl ICF Science Director

Don Correll ICF Planning and Communications Manager

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ICF FY 1997 Program Overview

J. D. Kilkenny
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Introduction

The continuing objective of Lawrence Livermore National Laboratory's (LLNL's) Inertial Confinement Fusion (ICF) Program is the demonstration of thermonuclear fusion ignition and energy gain in the laboratory and to support the nuclear weapons program in its use of ICF facilities. The underlying theme of all ICF activities as a science research and development program is the Department of Energy's (DOE's) Defense Programs (DP) science-based Stockpile Stewardship Program (SSP). The mission of the U.S. Inertial Fusion Program is twofold: (1) to address high-energy-density physics issues for the SSP and (2) to develop a laboratory microfusion capability for defense and energy applications. In pursuit of this mission, the ICF Program has developed a state-of-the-art capability to investigate high-energy-density physics in the laboratory. The nearterm goals pursued by the ICF Program in support of its mission are demonstrating fusion ignition in the laboratory and expanding the Program's capabilities in highenergy-density science. The National Ignition Facility (NIF) project is a cornerstone of this effort.

One of the more important aspects of ICF research is the national nature of the program. LLNL's ICF Program falls within DOE's national Inertial Confinement Fusion Program, which includes the Nova and Beamlet (LLNL), OMEGA (University of Rochester, Laboratory for Laser Energetics [UR/LLE]), Nike (Naval Research Laboratory [NRL]), and Trident (Los Alamos National Laboratory [LANL]) laser facilities. The Particle Beam Fusion Accelerator (Z) and Saturn pulsed-power facilities are at Sandia National Laboratories (SNL). In addition, General Atomics, Inc. (GA) develops and provides many of the targets for the above experimental facilities.

LLNL's ICF Program's research and development activities fall principally into two broad program elements and two main laser facilities: (1) target physics

and technology (experimental, theoretical, and computational research) and (2) laser science and optics technology. Experiments on the Nova laser primarily support target ignition and high-energy-density physics research. Experiments on LLNL's Beamlet laser support laser and optics science and technology development.

The target physics and technology activities are directed to ensure the success of achieving ignition on the NIF and supporting the science mission of the DP SSP. The activities fall into three main areas: Nova target ignition physics, code development and theory, and NIF target area technology development. The ICF Program and scientists in LLNL's A Division, B Division, V Division, and H Division, as well as high-energy-density scientists from LANL, collaborate on high-energy-density physics experiments on Nova.

The laser science and optics technology activities are directed towards providing laser and optics technology developments, validated performance models for the NIF, and advanced ICF laser systems. Laser developments have non-ICF spin-offs that are also valuable to Stockpile Stewardship, other national programs, and U.S. industry. Many of these spin-offs, which have then been advanced by other sponsors, are now being applied to ICF needs (i.e., spin-backs). The ICF Program is strengthened by this synergistic exchange of information between these diverse activities.

In addition, ICF sciences and technologies, developed as part of the DP mission goals, continue to support other DOE objectives. These objectives are to achieve diversity in energy sources through inertial fusion energy (IFE) research and to maintain a competitive U.S. economy through new development of technologies of interest for government and industrial use, including those developed through the Laboratory Directed Research and Development program.

This overview is divided into the following sections: Target Physics and Technology, Laser Science and Optics Technology, the National Ignition Facility Project, Inertial Fusion Energy/New Technology Applications, and Program Resources and Facilities. These sections summarize the findings within the many articles written for refereed journals and the ICF FY97 Quarterly Reports and also summarize important results from FY 1997 that have not been covered explicitly in the articles. Because of the national collaborations, many of the articles are coauthored with colleagues from other laboratories.

Target Physics and Technology

The Target Physics and Technology Program includes: (a) target ignition physics on Nova at LLNL and the OMEGA laser at the University of Rochester, (b) Nova high-energy-density experiments, (c) applications of ultrahigh intensities lasers, (d) code development and theory, and (e) NIF target area technology development. A small number of shots (approximately 10% of Nova shots) are devoted to the Science (University) Use of Nova Program in support of Stockpile Science.

Target Ignition Physics

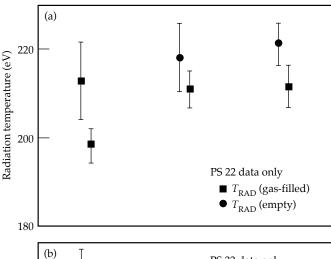
During the past year LLNL, LANL, SNL, UR/LLE, and NRL have begun the development of a detailed plan to reach ignition on the NIF. This National Ignition Plan, which has been incorporated into a Work Breakdown Structure (WBS), is divided into four subject areas—WBS1: Hohlraum Energetics, WBS2: Hohlraum Symmetry, WBS3: Capsule Optimization, and WBS4: Ignition Implosions/NIF Target Design. Although this plan is still under development, it has been effective in delineating high-priority activities in target design and fabrication and near-term Nova and OMEGA experiments. This WBS is used in our internal resource planning and Nova shot allocation.

Hohlraum Energetics

In the areas of Hohlraum Energetics and Hohlraum Symmetry, we have made significant advances in our understanding and control of laser/target interaction using "smoothed" laser beams. At the beginning of FY97, we installed kinoform phase plates (KPPs) and activated temporal smoothing by spectral dispersion (SSD) on all 10 beams of Nova. In collaboration with the Commissariat a L'Energie Atomique (CEA), we conducted a series of experiments with gas-filled hohlraums that were designed to emulate conditions encountered in NIF targets. In these experiments, we demonstrated a dramatic decrease in backscattered laser light in gas-filled hohlraums, resulting from stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS), and a corresponding improvement in laser/target coupling. When these targets were driven with shaped laser pulses reaching peak intensities of $4 \times 10^{15} \text{ W/cm}^2$, total laser

backscatter losses were reduced from 18% for unsmoothed laser beams to the 3% level for KPPs plus SSD. Peak-power losses were as small as 5%. Consistent with the increased laser power delivered into the hohlraum, we observed that the radiation temperatures increase by ~15 eV for smoothed laser beams, as shown in Figure 1.

For gas-filled hohlraums driven with laser pulse shape no. 22 (PS 22) at 1.8 terawatts (TW) peak power, we observed peak radiation temperatures in excess of 210 eV, and for PS 26 (2.6 TW peak power), radiation temperatures larger than 230 eV were measured. The radiation temperatures of both gas-filled and empty hohlraums were seen to compare well to each other and follow the Marshak scaling for ablative heat waves. In addition, the temporally resolved measurements of the x-ray production in gas-filled hohlraums is reasonably well described by radiation hydrodynamic LASNEX code modeling when the laser scattering losses are included in the simulations. The experimental peak temperatures agree with the LASNEX



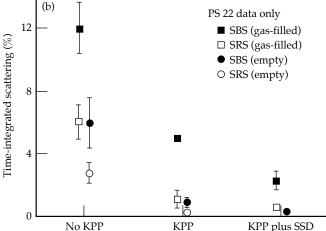


FIGURE 1. A comparison of radiation temperatures and time-integrated scattering percentages for laser beams without KPP (no smoothing), with KPP, and with KPP and SSD. (08-00-0598-1093pb01)

modeling, with a standard deviation of 4 eV, thus increasing our confidence in calculations for future inertial confinement fusion experiments.

We made several advances in the area of hohlraum characterization during FY97. We used Thomson scattering to measure electron and ion temperatures and macroscopic plasma flow in the low-Z plasma of hohlraums, driven by unsmoothed heater beams. We also developed a new 4ω Thomson scattering probe beam that will be used to study plasma conditions in hohlraums driven with smoothed Nova beams in FY98. In addition, we developed a spectroscopic technique to infer the time-dependent, hot-electron fraction in gas-filled hohlraums. These spectroscopic measurements are in good agreement with hot-electron measurements inferred from absolute measurement of SRS and bremsstrahlung emission.

Hohlraum Symmetry

The Hohlraum Symmetry Project achieved advances in two areas—symmetry improvements in gas-filled hohlraums and symmetry control by beam phasing.

Beam smoothing on Nova, described above, was shown to have a positive impact on hohlraum radiation symmetry in gas-filled hohlraums. Previous measurements using unsmoothed Nova beams had showed evidence of laser beam deflection, leading to an outward "shift" in the beam spots on the hohlraum wall and an overall asymmetry in the time-averaged radiation drive on the capsule. Although these experiments had shown that this asymmetry could be corrected by repointing the beams to account for the deflection, an understanding of, and a method to reduce or eliminate the deflection, was desirable. Theoretical work at LANL² and LLNL had suggested that the deflection was the result of beam filamentation in a flowing plasma. Using a 3D laser filamentation and propagation code called F3D, we predicted that beam smoothing should reduce filamentation and significantly reduce the beam deflection. This prediction was confirmed by a series of experiments led by LANL, in which capsule distortion was measured in gas-filled hohlraums driven by smoothed laser beams (KPPs only). The deflection was reduced by a factor of ~4 compared with the unsmoothed beam results.³

A crucial component of the Hohlraum Symmetry Project is the control of time-dependent flux asymmetries imposed on the imploding capsule. ^{4,5} During this past year, we began experiments to demonstrate continuous symmetry control on the Nova laser using a two-ring-pair NIF-like illumination geometry. Time-dependent symmetry was principally inferred from the distortions imposed on a backlit foam ball acting as a capsule surrogate. ⁶ The results demonstrated mitigation of the two lowest-order Legendre harmonic distortion coefficients (a₂ and a₄) relative to traditional

single-ring pair irradiation, in agreement with simulations. A simpler, rudimentary demonstration of time-dependent control of the lowest-order flux asymmetry in hohlraums was also performed on the OMEGA laser facility. The flux asymmetry was inferred from the shapes of x-ray images of imploded cores and from backlit foam balls. By minimizing the symmetry swing, the second-order Legendre distortion a_2 was kept below $2 \pm 1~\mu m$ at all times. The $\pm 1~\mu m$ accuracy is sufficient to detect distortion levels acceptable for ignition capsules. Future campaigns in 1998 will concentrate on using the technologies developed in 1997 to reduce random and intrinsic hohlraum flux asymmetries to demonstrate improved implosion performance.

Capsule Optimization

Correct timing of the ablatively driven shocks in the target is critical in achieving ignition on the NIF. This activity is primarily devoted to the development of techniques for this measurement on the NIF. A secondary goal of this project is to test and improve the physical databases [equation of state (EOS), opacity] of the ablator materials and fuel. More accurate knowledge of this information will allow for improved numerical simulations, thereby potentially reducing the amount of time required to achieve ignition on the NIF. In FY97, we continued work, begun the previous year, to test the accuracy with which we can follow shocks in D_2 and to map out the D_2 EOS near the first shock state of the NIF. We have developed and refined several techniques for these measurements, and in collaboration with the Laboratory's weapons program, have measured the shock velocity, particle velocity, density, temperature, and reflectivity of D_2 on the principle Hugoniot up to 2.4 Mbars (see Nova High-Energy-Density Experiments section). These measurements, which confirmed the higher compressibility of D₂ observed in our previous experiments, resulted in enhancing the "safety" margin in the NIF ignition designs due to the increased fuel compression.

Ignition Implosion/NIF Target Design

The majority of the efforts in Implosion Physics have been directed towards further advances in computational design work and fabrication techniques for the NIF. In the area of NIF target design work, we performed a systematic study that compared the effects of hydrodynamics instabilities seeded by three dimensional (3D) multimode surface perturbations on three similar NIF ignition capsule designs, each driven at 300 eV. The principal difference in these designs is the choice of ablator material that sits outside the deuterium-tritium (DT) ice layer: Br-doped plastic, polyimide ($C_{22}H_{10}N_2O_4$), and Cu-doped beryllium (Be). The computational tool used for this study is the 3D radiation hydrodynamic plus thermonuclear burn code named HYDRA. Multimode perturbations were

applied (modes l = 15 to 120) on both the inner surface of the DT ice layer and on the outer surface of the ablator. All three capsules ignited and burned, resulting in near-1D yields for initial surface finishes equal to the best achieved to date on a Nova capsule ablator and on cryogenic DT ice. The beryllium ablator design is most tolerant of increased initial surface roughness. These 3D calculations were done in a wedge-shaped region that was 12 degrees wide in each angle. As the 3D code is further parallelized and Accelerated Strategic Computing Initiative (ASCI) class machines progress in their capabilities, full capsule simulations can proceed that include the effects of longer wavelength modes from both hydrodynamic instability growth and drive asymmetries.

The effort to identify NIF target designs driven at 250 eV using lower laser intensity and less laser energy than the 300 eV designs discussed above continued this year. These designs offer potentially improved safety margins with respect to laser–plasma instabilities as well as laser energy performance. Thus far, the target that successfully ignited in these integrated calculations was driven with only 900 kJ of energy and a peak power of 250 TW, half the nominal energy and power for the NIF. Rayleigh–Taylor (RT) analysis of this design shows that it will require surface finishes that are beyond current demonstrated capabilities.

This year, we continued our work in support of identifying a beam arrangement on the NIF that allows the baseline hohlraum geometry as well as tetrahedral hohlraum geometry with direct drive. This work concentrated on designing a capsule implosion driven by a tetrahedral hohlraum experiment at UR/LLE's OMEGA laser. Once again, the 3D code HYDRA with its new 3D ray tracing postprocessors (to simulate the x-ray emission data) was used to successfully design and analyze the effect of the tetrahedral hohlraum drive asymmetry on the imploding capsule. Changes in tetrahedral hohlraum geometry (e.g., hohlraum wall radius, size of laser entrance holes, etc.) led to a change from a decidedly triangular shaped x-ray image of the capsule implosion to a round one, as per predictions.

Nova High-Energy-Density Experiments

In FY97, we fielded several diagnostics on Nova to test the precision with which we can follow shocks in D_2 and to map out the D_2 EOS near the first shock state of the NIF. In collaboration with A Division, B Division, and the Physics Directorate, we measured the shock velocity, particle velocity, density, temperature, and reflectivity of D_2 compressed on the principle Hugoniot up to 2.4 Mbar. These experiments were performed in the Nova two-beam facility and used a KPP to produce planar shocks. The compression, shock speed, and particle speed were measured to a few percent accuracy

with a high-resolution Kirkpatrick–Baez microscope. The temperature was measured to about 10% with the multichannel pyrometer. Shock emission intensity, I, is also a sensitive probe of shock steadiness since $I \approx v^8$. Finally the shock velocity (measured to 1 to 3% accuracy) and the reflectivity of shocked deuterium were measured with a velocity interferometer (VISAR).

The compression measurements revealed that liquid D₂ compresses nearly sixfold for a 1-Mbar shock; this is significantly more than most models predict. The first shock for a NIF implosion occurs near this maximum in fuel compression. The shock temperature, which is a good probe of the fuel entropy, is also lower than standard EOS tables (i.e., SESAME) predict. Finally, VISAR clearly shows that D₂ shocked to 1 Mbar has a high reflectivity (~60%). Thus the low-shock temperature and high-shock compression result as the unshocked molecular-insulating phase transforms to the shocked atomic-conducting phase. We are analyzing these data and working with the Physics Directorate to incorporate these data into a new EOS table for D₂. Finally, we are analyzing the optical emission and reflectivity data to determine fuel electron ion equilibration rates that have impact on thermal conduction mechanisms for the shocked fuel.

In collaboration with A Division, Physics, and LANL, we have made single-shock absolute EOS measurements on CH and Be at pressures above 10 Mbar using indirect drive and a preliminary EOS measurement on beryllium near the first shock of the NIF using direct drive. The Be experiments overlap well with quotidian equation of state (QEOS) and previous measurements of Nellis et al. nuclear tests. The CH experiments overlap with QEOS but deviated significantly from the standard preferred EOS table. These data caused a new preferred EOS table for CH to be constructed.

High-Intensity Laser–Matter Interaction

High-intensity laser-matter interaction was given significant emphasis in FY97. The Nova laser had previously been adapted to operate with chirped-pulse amplification (CPA) for ultrashort pulse generation on two such beamlines. The 100-TW beamline, routed to the Nova two-beam target chamber, was capable of delivering a maximum energy of 40 J in a pulse length of ~0.45 ps, producing focused intensities on target of up to 4×10^{19} Wcm⁻². The "Petawatt" (PW) (quadrillionwatt) beamline, utilizing Nova's beamline 6, was modified to operate with 70-cm-diam compression gratings, capable of delivering up to 500 J in 0.5 ps and thus a record 1-PW power. This significant milestone was reached in December 1996 and was the prelude to the first experiments with the exciting and unique PW laser. A dedicated target irradiation chamber in which the PW beam was focused with an f/3 on axis parabolic mirror

was constructed for this purpose, and the first target irradiation shots were fired in April 1997.

Science with the 100-TW and PW beamlines in FY97 emphasized two main themes. The first was fast ignition, a new approach to inertial fusion using short-duration, high-intensity laser pulses to ignite a DT target via an ignition spark formed at the focal spot of the laser on the surface of the compressed DT fuel.⁸ Valuable results were obtained on the characteristics of the hot electron source and on the heating effect of the hot electrons.

The second was MeV radiography using the energetic electrons produced at a high-intensity focus to generate MeV x rays in collisions with high-Z nuclei. The uniquely intense MeV photon source created in this way has the potential to provide multiaxis, multipulse MeV radiographs of great interest for advanced hydrodynamics research and to be competitive with MeV relativistic electron beam generators more conventionally used for this purpose. The intensity and spectrum of the x-ray source were measured, and test radiographs were recorded through massive lead objects.

FY98 will see significant improvement of the Petawatt to reduce the focal spot to near-diffraction-limited quality using deformable optics. The aim then will be to carry out new experiments to more definitely determine both the short-term feasibility of MeV radiography and the longer-term feasibility of fast ignition.

Code Development and Theory

Work in the area of advanced code development continues in support of the overall Stockpile mission. As described above, the capsule-only 3D radiation hydrodynamics code HYDRA has had new physics algorithms as well as postprocessors added to it. In addition, it had been extensively modified and enhanced to run on distributed memory platforms.

New finite element diffusion operators have been added to enable simulations on more general multiblock meshes in both 2D and 3D. This multiblock mesh structure, plus future additions of a laser deposition package, will enable integrated hohlraum simulations.

A complementary code development approach, funded principally by the ASCI Program, is the general purpose 3D radiation hydrodynamics design code named Kull. This code will use many of the physics modules that have been developed as part of its precursor project, ICF3D. During this past year, the ICF3D hydrodynamics has undergone intense validation testing against a suite of analytic and other well-known test problems. Progress has also been made on its mesh generator.

The main-line ICF design code LASNEX has also undergone important new developments. New magnetic field treatments have allowed us to do simulations of the effects of such fields on the plasma conditions in hohlraums. With new automated continual rezoning

schemes, we have also done simulations of more complicated flows, such as those that occur in hohlraums and in many other applications—laser medical tissue modeling, for example. We have also implemented material strength models for studying low- to moderate-energy-density physics this year. This new modeling capability in LASNEX is important not only to the SSP, but to industrial applications and spin-offs as well.

The new plasma code bZOHAR had many diagnostic capabilities added to it, which helped when it was used in production mode this year. It is a fluid electron, particle ion version of the 2D fully particle in cell (PIC) ZOHAR code. It was used to study the nonlinear saturation behavior of Brillouin scattering including effects of 2D versus 1D ion-wave-coherence collapse, in which it identified an ion-decay instability that facilitates this collapse. Direct comparison of this code's predictions for Brillouin scatter for cross-beam experiments was carried out as well, with good agreement with the measurements.

The 2D fully PIC ZOHAR code was used in studies of fast-ignitor channeling. New diagnostics such as particle trajectories were added that greatly elucidated the physics of the channeling process.

The 3D laser filamentation and propagation code F3D also underwent important new developments. The first models of Raman–Brillouin scattering instability competition were implemented and showed promising results, namely trends of competition that are similar to the observed ones. In addition, relativistic effects were included in the code to allow a study of fast-ignitor channeling on longer-scale lengths and time intervals than those of which the PIC codes are capable. The most important application of the F3D code was in its predictive capability of the role that beam smoothing such as binary phase plate and KPP beams play in the remediation of beam deflection in flowing plasmas. This has been confirmed by Nova experiments.

NIF Target Area Technology

The NIF target area systems include the 48 indirect-drive final optics assemblies, the target chamber, the target positioner, the target diagnostics, and various structures such as mirrors and beam tubes. These target area systems must provide optomechanical stability, incorporate the required target diagnostics, manage the laser light at all three frequencies, protect the optics, and provide radiation shielding. Also included in the target area technologies is the fabrication of the ignition target (hohlraum and capsule), including smooth cryogenic layers of DT as the inner capsule layer.

NIF Diagnostics Developments

A number of diagnostic instruments have been developed both for target physics experiments at OMEGA and as prototypes for NIF instruments. The Neutron Temporal Diagnostic (NTD) on Nova was reconfigured to operate as a standard diagnostic on the OMEGA target chamber. The NTD at OMEGA now provides a reaction history measurement for implosion experiments and will become a crucial platform for developing a NIF reaction history instrument based on the 16.7-MeV DT gamma-ray. A conceptually new neutron time-of-flight (nTOF) array has also been developed for experiments on OMEGA. Neutron sensitivity is achieved by adjusting the detector volume at a common location relative to the target chamber rather than by adjusting the target-detector distance as is done on Nova. In this way, it is hoped that yield and temperature uncertainties from background sources can be minimized. Finally, an assessment of readout systems for a charged particle spectrometer has been completed in parallel with the fabrication and detailed mapping of two spectrometer magnets. The dynamic range of the new charged particle spectrometers includes both DD alphas (<1-MeV) as well as DT tertiary protons (<30-MeV).

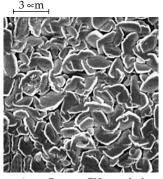
Additional prototype instruments have been tested to assess technology applicable for NIF instrumentation. A new version of a threshold Cherenkov gammaray spectrometer has been developed that employs a small magnet to eliminate low-energy Compton electrons before the Cherenkov radiator. Work also continued on the development of new technologies for neutron spectroscopy at the NIF. A prototype siliconbased instrument has been developed at OMEGA for testing in 1998, and an assessment of the resistive plate counter efficiency and response uniformity is under way at LLNL.

A number of new diagnostics have been developed for the PW fast-ignitor and radiography experiments. These include pin-diode and scintillator/photomultiplier tube-based instruments for measuring the intensity and angular distribution of hard photons emitted from the PW targets. Radiochemical techniques have also been applied to study the activation of target materials in the PW experiments. Additional radiochemical techniques (e.g., gas sampling) are also being evaluated as future NIF diagnostics.

Finally, direct neutron damage has been measured in a charge-coupled device (CCD) camera for NIF-relevant fluences at the rotating target neutron source. A total neutron flux of 10^{13} n/cm² demonstrated that single-shot damage is likely in an unshielded camera just outside the NIF target chamber. Indeed, single-event upsets were observed for flux rates as low as 10^9 n/cm²/second. Future analysis and experiments should clarify the shielding requirements for reliable CCD operation inside the NIF target bay.

NIF Ignition Capsules

We have continued to develop a variety of technologies for fabricating NIF ignition capsules. We completed investigating whether interfacial polymerization reactions between components dissolved in a spherical fluid drop and a supporting immiscible medium could produce high-quality plastic shells. Shells of the proper size were easily prepared, but the complexities of the interfacial chemistry made control of the surface structure difficult. We also adapted microencapsulation techniques, long used in the ICF community for submillimeter shells, to the production of NIF-quality 2-mm-diam shells and investigated the effects of processing parameters on the shell quality. We increased our effort to develop Be shells and worked to optimize the surface finish of Cu-doped Be-ablator sputter deposited onto plastic mandrels. Using bias-deposition techniques, thick coatings of this material with surface finishes better than 50 nm rms have been produced, with improvements over unbiased coatings as seen in Figure 2. By incorporating small quantities of boron in sputtered coatings, we have produced smooth, glassy films on flat substrates, which may lead to improved surface and bulk structures on coated spheres. We initiated a program to develop NIF-thickness, high-strength polyimide plastic coatings using vapor deposition techniques that were pioneered in the microelectronics industry for very thin (\sim 1 μ m) coatings. Thicker polyimide coatings on spherical mandrels, if strong enough and resistant enough to the beta decay, would allow for the roomtemperature handling of the capsules with DT gas fills (~1000 atm) sufficient to produce the required 80-μm DT ice layer when cooled to cryogenic temperatures in the target chamber. This would considerably simplify the cryogenic fielding of the targets.



6-∝m Be on a CH mandrel No bias rms roughness ~150 nm



9-∞m Be on a CH mandrel 120-V bias rms roughness ~40 nm

FIGURE 2. A comparison of bias-deposition coatings with unbiased coatings on plastic mandrels. (08-00-0598-1094pb01)

Cryogenic Technologies

All known NIF single-shell ignition target designs require smooth cryogenic layers of DT as the inner capsule layer. In 1997, we demonstrated for the first time that ~100-µm-thick DT layers can be formed with surface roughness rms ~1 μ m on the inside of millimeter-scale plastic spherical shells. These smooth layers (Figure 3) were formed by a new nucleation and growth process and did not require external enhancement techniques such as joule or infrared heating. We also demonstrated for the first time that by infrared heating the collisioninduced molecular vibration absorption in solid HD (which has no natural beta layering), ~100-μm-thick HD layers can be formed with surface roughness rms ~1.5 μ m, again on the inside of millimeter-scale plastic shells. From crystal growth experiments on flat substrates we found that surfaces of hydrogen crystals are significantly different than other van der Waals solids such as the rare gas solids. Typically, rare gas solids have no stable facets at temperatures higher than 0.8 times their triple point temperature. We observe that two different crystal orientations have stable facets at temperatures higher than the triple point temperature. Understanding the physics of these surfaces is important to assessing our ability to control the fuel surfaces in ignition targets. Finally, we have designed and analyzed thermal characteristics of cryogenic hohlraums for beta-layering fuel in ignition capsules and are nearing completion of a cryogenic test system for development of cryogenic hohlraums.

NIF Target Chamber Development

A protection scheme for the target positioner was validated by modeling and experiments in collaboration with the French CEA. The concept uses a thin centimeter-diameter B₄C disk backed by a crushable aluminum foam to reduce ablated mass and the intensity of the shock wave to acceptable levels. More stringent outgassing requirements caused a reevaluation of plasma-sprayed B₄C as the first-wall material. Only minor reduction of the outgassing was achieved by potential vendors. Although progress was made reducing the cost of hot-pressed B₄C, which would meet outgassing requirements, more significant was a discovery that a thin Ni-free, stainless-steel first wall would meet neutron activation requirements. Consequently, louvered stainless steel designs are being evaluated for both first-wall and beam-dump applications. Laboratory-scale to NIF-scale tests of beam dump concepts indicate that stainless-steel louvers, as in Figure 4, provided the best compromise for minimizing cost, mass of ablated material, and risk of catastrophic failure, compared to teflon-covered B₄C and silica-covered absorbing glass. Neutronics calculations continued to support construction design and material choice. They also showed that the current chamber-shielding design meets prompt neutron dose limits for operational personnel, and they were used to develop a retrofit plan for additional shielding if needed.

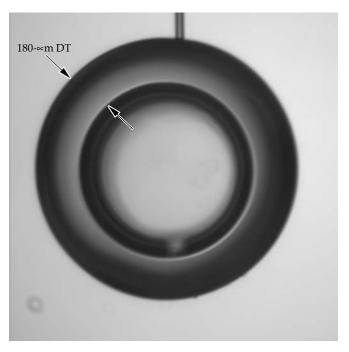


FIGURE 3. Smooth DT layers formed by a new nucleation and growth process without external enhancement techniques. (08-00-0598-1095pb02)

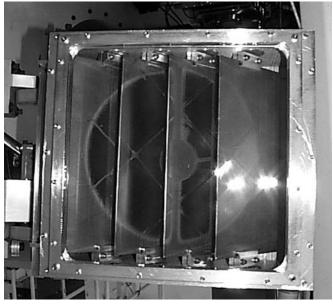


FIGURE 4. Tests showed that stainless-steel louvers provided the best compromise for beam-dump applications. (08-00-0598-1126pb01)

Science (University) Use of Nova

The Science Use of Nova Program is intended to make the Nova facility available to the outside scientific community for high-energy-density science investigations; 1997 was the second year that this program has been in place. As in the previous year when the program was referred to as the University Use of Nova, a call for proposals for Nova use was sent to scientists interested in the field of laser-matter interaction and high-energy-density physics, primarily at U.S. universities and to the membership of the Division of Plasma Physics of the American Physical Society. We received a total of 29 proposals from over 70 researchers at 33 different institutions. The proposals covered a diverse range of topics in high-energy-density science, including astrophysics, hydrodynamics, material science, and atomic physics. The proposals were reviewed and ranked by an external advisory committee made up of senior scientists from outside laboratories and universities. Based on their recommendation, the LLNL ICF Program accepted eight of the proposals for Nova shots. During FY97, approximately 10% of Nova shots were in support of these experiments.

Astrophysicists have shown strong interest in Nova experiments in the Science Use of Nova Program. Researchers from the University of Colorado and the University of Michigan are conducting experiments on the Nova laser to benchmark astrophysical codes used to model the radiative hydrodynamics of supernova remnant (SNR) evolution. Of particular interest is the SNR now developing around SN1987A. The ejecta from this supernova is on a collision course with its circumstellar ring nebula, with impact expected within five years. The astrophysics codes being used to predict the outcome of this extragalactic collision are being benchmarked with experiments on the Nova laser, where 1 ns (from the laser experiment) scales to 1 year for the SNR, 100 km/s to 10^4 km/s , and $100 \mu \text{m}$ to 0.03 light years. Initial experiments were conducted in 1D, to observe ejecta plasma flowing into a low-density ambient plasma, forming a classic forward shockreverse shock system, much like in the astrophysical SNR. These first experiments are described in a preliminary overview paper⁹ with details given in a set of recently submitted follow-up papers. ¹⁰ The group is now planning 2D experiments to study the RT instability predicted to occur at the contact discontinuity between the forward and reverse shocks. Such RTinduced clumping could change the nature of the much awaited collision from a smooth, 1D sweeping up of the ring, to something more akin to "hydrodynamic bullets" impacting the ring, in radiative bursts or "sparkles."

Researchers from the University of Arizona continue to develop experiments using the Nova laser at LLNL to

answer specific questions about hydrodynamic instabilities, in particular the RT instability, as is relevant to the evolution of core-collapse supernovae. In particular, the high velocities of the core elements Ni, Co, and Fe in SN1987A are still unexplained (3000 km/s observed, versus predictions of about half that) and may have a bearing on the observed light curve. In collaboration with ICF researchers from LLNL, the Arizona researchers conducted experiments on the Nova laser to test the hydrodynamics of the supernova code PROMETHEUS. Initial 2D experiments have been successfully completed and are described in several papers and conference proceedings. 11 The group is now turning to the crucial question of how the instability evolution in 3D differs from that predicted in 2D. This dimensionality could hold the key to unlocking answers to some of the remaining questions surrounding SN1987A. If the velocities of RT spikes in 3D are significantly larger than 2D predictions (note, 3D star calculations are still beyond current computational capabilities), this could enhance the mixing in the exploding star and help explain the observed light curve from SN1987A. Furthermore, any progress in advancing our understanding of the time-dependent mixing could shed light on the mechanism by which supernovae explode at all. Initial experiments to compare RT-induced mixing in 3D versus 2D in a hydrodynamic setting similar to an exploding SN are planned for the coming year.

NIF Laser Science and Optics Technology

In the Laser Science and Optics Technology (LS&T) area in 1994, we wrote a detailed "Core Science and Technology Plan for Indirect Drive ICF Ignition," which described the developments needed over the next four years to ensure the success of the laser and optics technology utilized in the NIF. In 1997, the third year of this plan, developments have been successful and are on schedule for completion in 1998. Also in 1994, the Beamlet laser was completed to provide an integrated test bed of the NIF optical design. During the past three years, many performance features of Beamlet have been tested including power and energy limits, focal quality, failure modes, and some NIF prototype hardware. It is also anticipated that Beamlet's mission will be completed in 1998 and that the facility will be converted to a NIF amplifier assembly and staging area in 1999.

NIF Laser Component Development

NIF laser component development continued in 1997 on the optical pulse generator, the main amplifier, power conditioning, the plasma electrode Pockels cell, the beam control systems including alignment and wavefront control, laser diagnostics, and the Beamlet and Optical Sciences laser test facilities.

The NIF optical pulse generation system consists of an optical-fiber-based master oscillator, fiber amplitude and frequency modulators for pulse shaping, and a fiber amplifier network that delivers nanojoule-level inputs to the 48 preamplifier modules (PAMs). The PAMs include a regenerative amplifier and a multipass rod amplifier that, to meet NIF specifications, must generate 22-J output energy with stringent specifications on amplitude stability, temporal pulse distortion, and beam quality. The 4-pass amplifier has been redesigned using the 50-mm Nova-type rod amplifier. In 1997, we assembled an optical fiber ring oscillator with improved amplitude and wavelength stability and a smaller overall footprint. A set of three commercially developed fiber amplifiers were assembled in series into an optical circuit with an overall gain of 300. We tested a commercial arbitrary waveform generator that will be used to shape the optical signal into the appropriate ignition pulse. This electronic pulseshaping system, which was designed and developed at LLNL, creates a 25-ns signal from summing 96 impulses that are 250 ps apart. We evaluated several advanced approaches for improving the regenerative amplifier and modified the optical cavity to utilize a larger volume of the gain medium, reducing temporal pulse distortion. One advanced design results in twice the output energy with no increase in temporal distortion. We also demonstrated >25 J output from a 50-mm-diam, 4-pass rod amplifier system shown in Figure 5 with good beam quality and reduced temporal pulse distortion, which

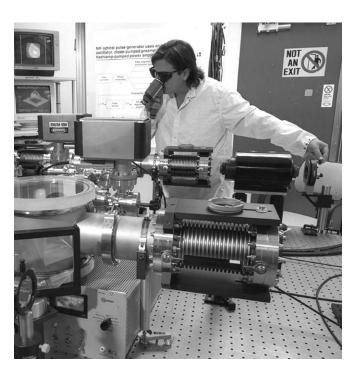


FIGURE 5. A 50-mm-diam, 4-pass rod amplifier system. (70-00-0598-1096pb01)

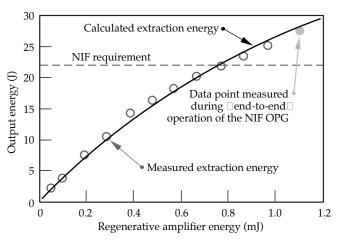


FIGURE 6. NIF OPG developmental system meets requirements. (40-00-1297-2585pb02)

exceeded specifications for the NIF (see Figure 6). The major goal for 1998 is to demonstrate the performance of a fully integrated, prototype optical pulse generation system.

We have constructed and commissioned a facility to test full-scale amplifiers for the NIF (see Figure 7). The worker in the background of Figure 7 gives an idea of the



FIGURE 7. NIF prototype amplifier under test in AMPLAB. (70-00-0997-1885#9pb01)

scale of the device. The Amplifier Module Prototype Laboratory (AMPLAB) will provide essential information about amplifier assembly, maintenance, and cleanliness requirements, as well as provide a key test bed for verifying the gain, gain uniformity, wavefront quality, and thermal recovery required for the NIF. The AMPLAB construction began in 1996, with assembly, cleanliness, and initial gain and wavefront measurements beginning in 1997. The facility is capable of testing a $4 \times 2 \times 3$ module array (four slabs high by two slabs wide by three slabs long), with an automated cart for loading cassettes of amplifier slabs while maintaining clean-room conditions and class-100 clean-room facilities for assembly and refurbishment.

The assembly and initial handling tests verified that proposed NIF cleanliness levels were achievable with this bottom-loading design. Slab and flashlamp cassettes were successfully loaded and unloaded from the frame assembly unit as pictured in Figure 7, transported to the clean-room facility, and refurbished as required, demonstrating the viability of each of those operations. Initial full-aperture gain measurements were performed on a $4 \times 2 \times 1$ configuration, with results in good agreement with our design codes and meeting the 5% / cm gain coefficient required for the NIF. A large-aperture diagnostic system (LADS) was assembled for these gain measurements in collaboration with our French CEA colleagues and was initially activated with a Twyman–Green interferometer for wavefront measurements (see Figure 8). To properly



FIGURE 8. Control console for U.S.-French large-aperture diagnostic system. (70-00-1197-2406pb01)

characterize the wavefront quality of the three-amplifier-long system, the LADS will be retrofitted with a high-resolution ($\lambda/100$) phase-shifting interferometer that is being provided by our CEA partners.

To increase the NIF's shot rate, it will be necessary to actively cool the amplifier flashlamps to reduce the time required for thermal distortions in the amplifier slab to diminish. We have conducted extensive tests on Beamlet to connect temperature rise with wavefront quality, developed detailed thermal models of the amplifier system, instrumented the AMPLAB facility with a thermal data acquisition system, and are now activating a flashlamp cooling system on AMPLAB. Very preliminary results from the AMPLAB tests verify the results obtained on Beamlet and small-scale offline amplifier experiments regarding flashlamp and amplifier slab temperatures. Additional investigations will verify our ability to effectively cool the flashlamp cassettes and measure the relationship between slab temperature and wavefront quality for comparison with our analytical models.

The NIF employs over 7000 flashlamps, which are 1.8 m long with a 4.3-cm bore, the largest commercial lamps ever produced. In 1997, we completed initial testing of such flashlamps from several vendors and determined that the use of a doped electrode in the anode as well as the cathode appears to significantly reduce anode sputtering, a source of premature flashlamp failure. Although some flashlamps have been tested for more than 20,000 shots, three lamps from one manufacturer failed catastrophically on initial AMPLAB gain experiments. These flashlamps were determined to have a flawed base assembly design. We have worked with the vendor to develop a design solution that will be implemented on future generation lamps.

The power-conditioning design for the NIF consists of approximately 200 modules, each supplying 1.7 MJ of energy. The development of this hardware is shared with SNL. During 1997, we activated a 22-station capacitor test facility and completed initial testing of capacitors from five different commercial vendors. Multiple vendors have been found that can meet NIF capacitor specifications. The NIF specification for the charging power supply was determined to be 25 kJ/s, and three commercial vendors produced prototype supplies that passed acceptance tests at that level. The NIF switch is required to handle 500 kA of current, and the switch test stand at SNL was used to measure various candidates. The NIF baseline spark gap, when fitted with a steel housing, displayed promise of meeting the requirement of 1000 shots before refurbishment. Although tests on a commercial rotating-arc-gap switch demonstrated superior performance, it will be necessary to reduce the cost of this device in order to meet NIF goals. Initial testing of a complete prototype power-conditioning module shown in Figure 9 has begun at SNL.

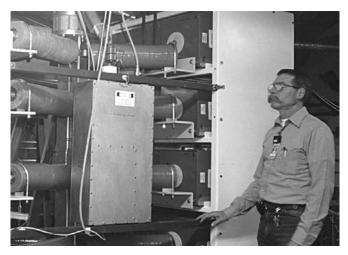


FIGURE 9. A complete prototype power-conditioning module at SNL. (70-00-0598-1097pb01)

The plasma electrode Pockels cell (PEPC) for the NIF is a 4×1 module that is electrically composed of two 2×1 modules that are stacked end-to-end as shown in Figure 10. During 1997, we demonstrated a 2×1 prototype module that greatly exceeded the NIF performance requirements with respect to average and minimum extinction ratio as measured from the residual unrotated polarization. A technique dubbed "magnetic spreading," whereby an external current was used to more uniformly spread the plasma across the electrode region, was beneficial in improving PEPC performance and will be incorporated into the NIF design. The development also verified the use of an anodized metal housing and a grounded cathode.

These features have been incorporated into the prototype 4×1 design, which has been procured and is now being assembled. We also developed a commercial vendor for both the switch and plasma power supplies that will be utilized on the testing of the 4×1 module. Successful testing of this prototype in 1998 will complete the PEPC development effort.

Aligning and controlling the 192 beamlines for the NIF in a cost-effective manner is quite challenging, requiring many new concepts and techniques. In 1997, a complete automatic alignment sequence was successfully executed on our 1/10 scale optical layout of a NIF beamline, verifying that the system has the required degrees of freedom to achieve the required beamline alignment time and precision for the various alignment steps. Both 1ω and 3ω alignment light sources and distribution networks have been developed, as well as precision positioners for alignment light sources and pinholes.

To achieve efficient frequency conversion and a high-quality focal spot on target, it is necessary to actively control the wavefront of the laser. We developed a 40-cm deformable mirror (see Figure 11) with 39 actuators, and in 1997 we installed and tested the device on Beamlet. Despite concerns, there was no degradation or evidence of prompt effects due to flashlamp light or electromagnetic interference. In addition, the advanced mirror controller was successfully integrated into Beamlet with only minor problems. However, the observed beam quality fell short of requirements due to residual error resulting from mirror fabrication problems. These issues are well understood and should be corrected in mirror rebuilding planned for 1998. In the meantime, we have been working with multiple vendors to produce prototype

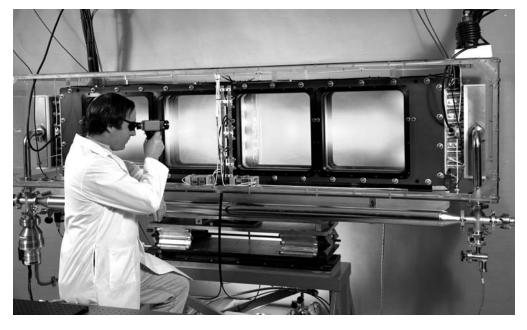
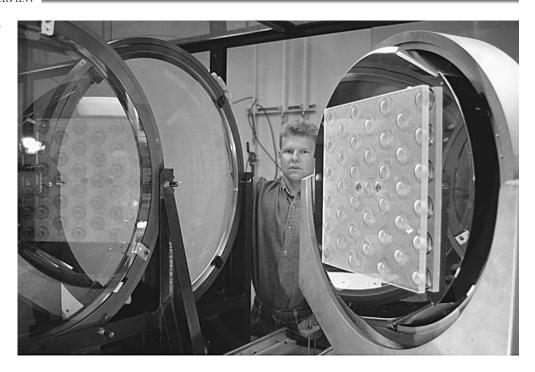


FIGURE 10. The plasma electrode Pockels cell for the NIF. (70-00-1297-2596#8pb01)

FIGURE 11. A 40-cm deformable mirror. (02-01-0897-1511#22pb01



large-aperture mirrors using different methods of actuation. These mirrors will be tested at LLNL in 1998.

Special diagnostic systems related to power balance and optical damage detection are being developed for the NIF. The NIF requires a high degree of amplitude stability among all the beamlines, specified as <8% rms difference during a 2-ns window for each of the 192 beams. In order to measure the power in a cost-effective manner, we are developing 1ω and 3ω optical fiber systems to deliver the light from various points in the optical chain to photodiodes in a temporally multiplexed manner. In 1997, we collaborated with Russian colleagues at the Vavilov Institute to develop special ultraviolet optical fiber that meets stringent requirements for attenuation (<300 dB/km) and dispersion (0.25 ps/m). For 1ω bundles, where acceptable fiber is readily available, our efforts have concentrated on developing inexpensive techniques to reproducibly measure fibers to within ±4 mm to produce bundles up to 70 m in length. Initial tests using an encoded wirelength measurement system verify that we are close to meeting that specification. The monitoring of the many costly optical components will be an important aspect of operations for the NIF. An on-line damage detection technique, which uses a dark-field Schlieren diagnostic to readily view the high spatial frequency portions of the beam produced by various optics in the chain, was designed and will be implemented on Beamlet.

Development of the NIF computer control system has concentrated on the overall system architecture and supervisory software framework. In 1997, we initiated a simulation of the integrated computer control

system to assess behavior using models of controlled equipment. The simulation will operate on a computer test bed to evaluate distributed performance under various configurations using emulations of actual control points. We also developed a prototype of the NIF integrated timing system, which successfully demonstrated the most critical aspects of the system, including 25-ps rms short-term timing jitter.

System Integration Tests on Beamlet

The major goals of Beamlet and the much smaller Optical Sciences laser are to validate the analytical models that we have developed to design the NIF laser system and to test laser designs and performance levels that are planned for the NIF. In 1997, several important Beamlet campaigns were completed. The 1ω portion of the laser system was optimized for wavefront quality using the small 7-cm deformable mirror positioned at the front end, resulting in a far-field spot radius <12 μr (80% energy containment). The largeaperture deformable mirror was installed, but due to excess residual error caused by assembly problems, the spot radius increased to 24 µr. Measurements performed on the transport spatial filter revealed onset of beam propagation effects at 10^{-3} Torr, resulting in the specification of a safe operating pressure for the NIF of 10⁻⁴ Torr. We also designed and tested several advanced pinhole designs. Measurements revealed that a ±150-µr stainless-steel conical pinhole passes a temporally shaped, 21-ns ignition pulse with no sign of closure during the pulse and with acceptable back

reflections more than 20 times less than those observed with "washer" or "leaf" designs. The backscatter growth was linear with output shot energy, and its farfield profile indicated that simple reflections that were from the pinhole annulus were responsible for backscatter rather than nonlinear laser interaction processes from the blowoff plasma. Additional effort will concentrate on optimizing the pinhole shape or using alternate materials in an attempt to provide even tighter spatial filtering. We performed experiments using 1D SSD to improve the uniformity of the focal spot and to minimize unwanted plasma scattering in hohlraum targets. To remain within a safe operating regime, these experiments were limited to B-integral values up to 70% of the NIF limits, and they revealed system behavior consistent with our analytical models.

Assembly, activation, and testing of the new final optics configuration was a major campaign in Beamlet as shown in Figure 12. Dubbed the "test mule," this hardware is intended to confirm several concepts for the NIF: use of a 1 ω input window with the frequency conversion crystals and 3 ω focusing lens mounted inside the vacuum, color separation and beam sampling gratings, and the general design techniques planned for the final optics hardware. Efficient conversion of the 1 ω light to 3 ω is a key laser performance specification for NIF. Initial tests in 1997 measured both 2 ω and 3 ω frequency conversion and revealed that both material

homogeneity and stress due to mounting the crystals were sources of the observed spatially nonuniform conversion. Also, initial thermal testing and analysis indicated that the design would result in acceptable recovery time for the crystals between shots. Finally, we installed an optical damage inspection system on all vacuum-loaded lenses and windows and a fail-safe bandwidth system to ensure safe operation and control-stimulated transverse Brillouin scattering in the optics.

Laser Modeling and Optimization

Having completed the cost-optimized laser design of the NIF in 1996, we spent most of this year refining the designs of specific components and carrying out the calculations needed to support the NIF Title I Design Reviews and baseline design changes. This work required numerous code improvements, extensive data evaluation, and extensive "number crunching," as well as close cooperation with the NIF engineering team.

In the main amplifier design effort, we completed pumping, storage, and parasitic codes needed to improve the predicted gain margin. A new 3D multi-wavelength code was brought on-line and was used to analyze improved reflector designs and blast shield treatments. A fast and efficient version was provided to the power-conditioning engineers to allow them to optimize their circuits for highest stored energy.

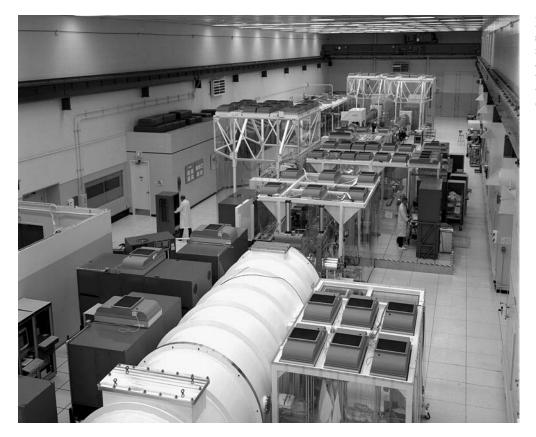


FIGURE 12. The Beamlet laser showing the full-aperture focusing diagnostic in the foreground and the "test mule" for testing, with the final optics design just upstream.

(70-50-1297-2574#3pb01)

The laser modeling team worked closely with the optical pulse generation engineers and used their propagation codes and optics database to supply designs with no temporal overlap and with acceptable output wavefront distortion. A high-fill-factor, small-spot-size beam shaper design was produced.

The calculation of risk due to point defects in the optics at various points in the chain was made practical by streamlined computational methods to carry out the extensive scans needed. Initial runs confirmed our ability to quantify the danger, and we are now carrying out a comprehensive analysis for all NIF optics.

The detailed specification of laser system optics, using spatial-frequency characterization of the phase aberrations, continued in close collaboration with vendors and the NIF optics team. The level of allowable distortion in various spatial frequency bands was refined to assure that the NIF meets its system design requirements.

Our adaptive optics simulation models have been continuously upgraded to simulate the sensing system, control algorithms, and actuator response more accurately. We have determined the optimal number of actuators to meet NIF specifications as a function of the quality of the optical components and supplied this information to the design engineers.

We performed analysis of the nonuniform frequency conversion results with large crystals on Beamlet and ruled out many potential sources of the problem as well as supplied the required instrument sensitivities needed to determine the real cause. The effect of conversion crystal mounting errors, gravitational sag, temperature differentials, and residual stress were evaluated to set specifications on the NIF crystal assemblies.

Propagation of beams through plasma near the spatial filter pinhole was added to our propagation codes to allow accurate analysis of pinhole blowoff. This capability will be used in conjunction with the existing ability in modeling beam profiles to determine the optimum size of various pinholes in the NIF laser chain.

NIF Optics Manufacturing

We are continuing the four-phase program started in 1995 to meet the NIF optics requirements: development, facilitization, pilot production, and production. Progress in development continues to be good in all areas, consistent with the NIF schedule. In parallel with program-funded development, most of the major optics manufacturing facilitization contracts funded by the NIF Project were awarded in 1997. Some of the equipment from these facilitization contracts has been utilized in the development program to permit demonstration of NIF prototype technologies at full size. Most of the facilitization will be complete in 1998 along with the development activities, leading to the pilot production runs in 1999.

Laser Materials: Phosphate Laser Glass, KDP/KD*P Crystals, and Fused Silica

In partnership with the French CEA, we continued working with two companies to develop continuous melting technology of platinum-free phosphate laser glass—Schott Glass Technologies in Duryea, PA, and Hoya Optics in Fremont, California.

Following Schott's efforts with LLNL in 1996 in developing an improved laser glass composition, LG-770, the primary focus in 1997 was preparing for a fullscale development run in the NIF melting facility constructed in 1997. The building and the furnace were designed and constructed in 1997 as part of the NIF Project facilitization effort. In parallel with these efforts, we worked with Schott to refine the material preparation process for efficient melting and to better understand the phase diagram in the vicinity of the NIF baseline composition to ensure the absence of devitrification in the melter. The raw materials for the development run were ordered and processed for the campaign anticipated in late 1997. The melter was heated up to its operating temperature without glass to ensure that the heaters and control system were operating properly. The results of the development run will be evaluated in early 1998 and used to modify the melter in preparation for the pilot production campaign in 1999.

Hoya worked with LLNL and CEA to evaluate phase interferograms of the half-scale laser slabs produced in 1996. These interferometry data were used by Hoya to modify the melter design to improve the homogeneity by roughly 2× the level needed to meet the NIF specifications. The modified melter was built and shipped from Japan to Hoya's Fremont facility for a final demonstration melting campaign in early 1998. During 1997, Hoya also completed their full-scale melter design, ordered the long-lead equipment, and built the production facility in Fremont. The NIF laser glass melter at Hoya will be constructed during 1998 and modified as needed based on the results of the final half-scale demonstration run in preparation for its pilot production run in 1999.

We also built, tested, and installed platinum laser damage testers at both Schott and Hoya for raster-scanning each piece of laser glass to qualify it for meeting the NIF platinum inclusion specification. These laser damage testers will be used to test the laser glass produced during Schott's and Hoya's development work in 1998.

In 1996, the potassium dihydrogen phosphate/potassium dihydrogen phosphate (deuterated analog) (KDP/KD*P) rapid growth program jointly sponsored by DOE and CEA produced the first boule large enough to yield Pockels cell plates for the NIF, with an approximate 43 to 48 cm² cross section. Plates fabricated from these boules met all the NIF optical specifications for the Pockels cell; four of these plates have

been installed in the 1×4 prototype plasma electrode Pockels cell. The primary issues remaining at the end of 1996 were the size needed for the second harmonic generation (SHG) plates, approximately 51 to 55 cm in cross section; the height of these boules expressed as an aspect ratio, which is height divided by lateral dimension; and the formation of solvent inclusions on the prismatic and pyramidal faces, which limit the yield of usable plates. Significant progress was made in 1997 on all three of these issues.

We grew several boules exceeding the NIF size requirement for the SHG plates, ranging from 53 to 58 cm in cross section. These results were enabled by further improvements of the original platform design based on Lucite, as well as by a new design based on aluminum with a Teflon-like fluorocarbon coating to prevent solution contamination. This aluminum design has replaced Lucite as the baseline rapid growth platform. Aluminum has two significant advantages over Lucite. First, at KDP growth temperatures, it is about thirty times stronger than Lucite, so the platform is significantly stiffer. Second, the thermal expansion coefficient is a nearly perfect match to KDP, so the thermal stresses induced in the boule as the temperature is reduced during the growth process are eliminated.

The SHG boules of KDP need to be approximately 51 to 55 cm tall to allow for several plates to be fabricated. Our standard initial growth temperatures of approximately 65°C tends to produce crystals that are somewhat shorter than these requirements due to the relative growth kinetics of the prismatic and pyramidal

faces. Higher initial growth temperatures of approximately 75°C favors fallen growth, but the use of Lucite platforms had precluded routine operation in this regime due to significant softening of the material. Aluminum platforms now allow us to operate at these higher temperatures. We have modified the seed regeneration conditions to further favor pyramidal growth by minimizing the number and strength of the prismatic dislocations. Shown in Figure 13 is a crystal grown under these conditions; this boule is approximately 52×53 cm laterally and 51 cm tall, limited in this case by the platform geometry. Our new aluminum platforms will allow the growth of boules up to 60 cm wide and tall, exceeding the NIF requirements. Most of this work has been performed with undeuterated KDP crystals, but similar findings are expected for KD*P in 1998.

The damage threshold of rapid growth KDP crystals significantly exceeds the NIF requirements in the infrared. In 1996, we found that continuously filtered KDP grown in our small tanks had a damage threshold at 351 nm, within about 20% of the NIF goal. This work was extended in 1997 and demonstrated that the use of high-purity salt coupled with continuous filtration leads to a 3ω damage threshold in rapid growth equivalent to the traditional manner, both of which exceed the NIF requirement. These results will be confirmed in a full-size boule grown in our large tanks in 1998.

Development activity is continuing to reduce the production cost of high-quality fused silica. Initial modeling and single-burner experimental efforts at Corning in 1996 to optimize their fused silica deposition process indicated that an improved burner should



FIGURE 13. KDP crystal. (40-00-0198-0133#19pb01)

allow for increased deposition rate and boule thickness. Tests in 1997 with the new burner installed in a large furnace confirmed these expectations, providing greater confidence in the Corning cost estimates for NIF fused silica production.

Polishing technology developed at LANL was successfully applied for grinding and polishing full-size Corning boules. This technique improves the inspection capabilities for bubbles and inclusions and enables the use of the polished homogeneity (PHOM) approach for refractive index uniformity instead of oilon plates.

Damage tests at 351 nm on fused silica with inclusions between 10 and 80 μ m indicated that the specification on inclusions (currently 80 μ m) may need to be tightened for some of the fused silica optics, particularly the focus lens and phase plate. In 1998, we will extend this study to refine our understanding of damage and its evolution with repeated high-fluence shots in bulk fused silica to refine the inclusion specification and inspection requirements.

Optics Fabrication: Flats, Lenses, and Crystals

Development activities in optics fabrication matured significantly in 1997. In plano optics (flats) and lenses, we continued to work with three companies—Eastman Kodak in Rochester, NY; Tinsley Laboratories in Richmond, CA; and Zygo in Middlefield, CT. We expect all three companies to play a major role in NIF optics fabrication. Facilitization contracts were awarded in 1997, which established the lead suppliers for each optic type. Zygo was selected as the lead supplier for amplifier slabs and mirrors, and Tinsley was selected for windows and lenses. Kodak is expected to provide a significant quantity of both flats and lenses as a secondary supplier to Zygo and Tinsley; their facilitization contract should be awarded in early 1998.

In 1996, Kodak improved its small-tool figuring capability, developed originally for classified and space programs, to meet the NIF power spectral density (PSD) specification. Kodak also demonstrated advanced continuous polishing (CP) technology on a subscale machine to improve the figure of the optical surface prior to small-tool final figuring. In 1997, Kodak completed the design and fabrication of full-size components needed to retrofit their large CP machine. This work was put on hold to permit Kodak to finish most of the large optics needed for the NIF interferometers. The CP retrofit is now scheduled to be completed in 1998. Two NIF-size spatial filter lenses were fabricated at Kodak; these lenses will be tested in 1998 to determine if they meet the NIF PSD requirement.

In 1997, Tinsley built and tested full-size prototypes of every finishing machine with the exception of the CP; the CP is scheduled to be completed in mid-1998. Prototype plano and lens optics fabricated on these

machines met all NIF optical specifications except for surface roughness. Reducing the roughness will be addressed in 1998. Tinsley completed four Beamlet spatial filter lenses that will be installed on Beamlet for testing in 1998.

In 1996, Zygo demonstrated each major processing step in its plano fabrication process on equipment ranging from half- to full-size. Improvements to Zygo's CP technology in 1996 significantly increased the determinism of the process, which will require fewer iterations in final figuring. In 1997, Zygo demonstrated a proprietary approach to improve this technology even further, providing much greater confidence in their NIF optics fabrication cost projections. This technology has been designed into the NIF CP machines currently under construction. A full-size electrolytic in-situ dressing grinding machine was also designed and constructed. Zygo also designed, built, and qualified the NIF cladding process fixtures.

The primary remaining technical issue in optics fabrication is the surface damage threshold at 351 nm. In 1997, we extended our finishing damage development activities in several ways. First, a two-pronged study was initiated at LLNL to investigate the impact of finishing parameters on 3 ω damage. One thrust focused on the use of a different slurry composition for final polishing, the second focused on a postpolish hydrofluoric acid etch of parts polished using traditional polishing slurry. Both approaches emphasized extreme care in removing residual subsurface damage from prior grinding and polishing steps. Work on small substrates indicated that both approaches can be used to fabricate fused silica optics that exceed the NIF requirement.

In parallel with the LLNL activities, several vendors executed development campaigns to extend their own proprietary finishing technologies with the goal of demonstrating robust processes for 3ω damage. While the details are proprietary, in general these processes involve both traditional processes as well as postpolish etching. Kodak, Tinsley, and Zygo all participated in this work, as well as two French companies, REOSC and SESO, that are working with the CEA. Work was performed with 15- to 20-cm optics to provide better feedback on scaleup as well as on full-size lenses and plano optics. All five of these companies produced optics at the 15- to 20-cm size or larger that were at or near the NIF 3ω specification, and two companies made optics that significantly exceeded the NIF damage requirement. Those companies are currently fabricating NIF-size focus lenses as well as NIF-size plano optics prototypes for testing in 1998. These results will be used to choose the NIF suppliers of focus lenses and 3ω plano optics for final facilitization in 1998/99.

Efforts in 1997 to develop improved diagnostics for damage threshold testing and damage mapping were also very successful. Of particular note is the demonstration of a mapping system that uses fiber-optic illumination, a megapixal camera for detecting artifacts as small as 5 μm , both in the surface and the bulk, and a long-focal-length camera to resolve these defects. This system has been adapted to our large-area damage testing system to permit real-time feedback on damage morphology and density for more rapid interpretation of 3ω finishing development.

Investigations into damage thresholds using total internal reflection microscopy started in 1996 were continued in 1997. In this effort, we are attempting to correlate the damage susceptibility of surface or nearsurface artifacts produced during polishing by comparing pre-illumination images with those after exposure to the high-fluence laser. Although this work is not completed, there is a definite correlation of "clean" surfaces with high-damage thresholds, while surfaces with a high density of artifacts tend to have low-damage thresholds. However, depending on the vendor, some surfaces with a moderate density of fabrication artifacts have high-damage thresholds, and some have quite low thresholds. Work is continuing in 1998 to better understand the nature of these defects and the associated damage mechanism(s).

In KDP/KD*P crystal finishing, development activities continued to make good progress. The current crystal finishing process at Cleveland Crystals, Inc. (CCI), based on single-point turning, produces crystals that meet the NIF specifications, but they are undersized for the NIF 41-cm crystals because they were originally designed for Nova 27-cm crystals. To meet the NIF requirements, we are working closely with CCI to modify the finishing process and to design and build the needed machine tools and metrology instruments. Of particular importance are the tools for establishing the crystal flatness, the final diamond turning machine that determines transmitted wavefront and surface roughness and the crystal orientation measurement system (COMS) for verifying the proper orientation of the crystal axes relative to the surface normal.

In 1997, we completed the conceptual design of the crystal flatness machine prototype and acquired most of the major components. The final design will be done in early 1998, and the machine will be assembled and ready for testing in the middle of 1998. A diamond-turning prototype machine, being built by Moore Tool, is approximately 75% designed with all the long-lead items on order. The design will be done in early 1998, and the machine is scheduled to be complete in late 1998. A conceptual design of a new COMS was completed in 1998. In the present COMS, the crystal orientation is measured at only two points on the crystal. This approach provides extremely little information about the variation throughout the crystal of the crystallographic axes with respect to the surface normal. Hence, the uniformity of frequency conversion

cannot be ascertained. A newly designed NIF COMS that will allow for scanning over the entire surface to produce a map of the variation of the crystal axes with respect to position is scheduled to be operational in mid-1998.

Optical Coatings: Mirrors, Polarizers, and Debris Shields

The primary coating development activities concerned defect reduction in 1996, stress reduction in 1997, and spectral control in 1998. Defect reduction for damage threshold improvement was accomplished by development of a starting material, metal hafnium, that has minimum source ejection during deposition. The coating stress has been reduced by optimization of the oxygen pressure during deposition. Improved spectral control will be accomplished by the development and installation of proprietary deposition process control instrumentation, improved deposition stability, and improved thickness calibration. Laser conditioning studies in 1997 were aimed at reducing the laser conditioning costs by minimizing the number of conditioning steps needed to meet the laser damage threshold.

In 1997, three groups successfully used the metal hafnium process to produce full-size mirrors for testing on Beamlet: Optical Coating Laboratory, Inc. in Santa Rosa, California; Spectra-Physics in Mountain View, California; and the UR/LLE in Rochester, New York. Further, these mirrors were also conditioned to the required damage threshold in a single step, rather than the six steps used for the original Beamlet coatings or the two- to three-step process envisioned last year.

Both Spectra-Physics and UR/LLE worked to produce full-size polarizer coatings in 1997. The polarizer coatings require much tighter control of the thicknesses of the individual layers to meet the spectral requirements. Even though this control is improved using metal hafnium source material rather than hafnium oxide, it is still extremely difficult. This difficulty impacts the yield and hence the cost of the process, rather than the performance. Both groups have identified the conceptual approaches they will use to improve the thickness control through the use of improved spectral monitoring with appropriate feedback to the coater. These technologies are scheduled to be demonstrated in development contracts in 1998. Nonetheless, Spectra-Physics and LLE were both nearly on schedule to produce their polarizers by the end of 1997 utilizing their existing technologies.

Damage testers were installed at the coating vendors to enable them to more rapidly evaluate the damage performance of their coatings for quicker process optimization during the remainder of development through completion of NIF production.

While not required until the NIF begins operating at high fluence with substantial target yields, work has started to identify concepts for protecting the final surface of the debris shield or for using an inexpensive film in place of a debris shield. Many types of potential strippable coatings were evaluated. All organic polymer coatings failed at x-ray fluences well below that required, even though their laser damage thresholds were adequate. A few inorganic coatings were also tested. By far the best was a sol-gel silica material prepared from tetraethylsilicate in a similar manner to our antireflective (AR) coating, except that acid hydrolysis was used. This resulted in a high-purity silica coating that was approximately 95% dense and that had a refractive index almost equal to the dense silica substrate. This coating can be applied using the same facilities as the standard sol-gel AR and is removed by etching in HF/NH4F solution or warm 10% sodium hydroxide solution. Initial experiments indicate no degradation of the surface damage threshold. The primary drawback to this approach is that the coating thickness is limited to about 1 µm, so some damage to the debris shield from target shrapnel can still be expected.

In parallel with the protective coating concept, we began an effort to identify a low-cost "disposable" debris shield. We screened several materials for x-ray damage, small-beam laser damage threshold, shrapnel penetration, thermal/laser decomposition products, optical transmission, and wavefront. A commercial DuPont fluoropolymer (FEP 100A) met all criteria except transmitted wavefront. We established a working relationship with DuPont to identify suitable ways to improve the wavefront of FEP 100A or find an alternative material.

Large Optics Cleaning/Sol-gel Coatings and Diffractive Optics

We performed experiments at the NIF-scale to define the cleaning and drying scheme for the NIF; these results were used to establish specifications for the NIF equipment. These experiments included slow-pull (capillary) drying speed as a function of temperature, particulate contamination levels achievable with our existing prototype cleaning system, bath contamination levels required to achieve NIF cleanliness specifications, and optics angle and fixture design for drip-free drying and sol-gel coating.

We demonstrated the NIF baseline aqueous cleaning processes for laser glass, dielectric-coated BK-7 glass, and fused silica on subscale optics using the LLE automated cleaning system and particulate cleanliness measurement tool. We also validated at full-scale the NIF ultrasonic-assisted laser glass cleaning process.

For KDP, we demonstrated the NIF cleaning process utilizing ultrasonic agitation on crystals for a refurbished Nova array. There was no degradation to the surface damage threshold, no fogging, or any enhancement of pre-existing scratches and digs. We have also demonstrated key elements of the NIF KDP crystal

spin-coating process on an 18-crystal Nova array. The NIF process requires development of high-damage threshold, slow-evaporation-rate colloidal silica sol-gel AR coating solutions. These lower-evaporation-rate solutions, in combination with spin-coater design advances, allow replacement of the current dip-coat process with a process capable of tailored coatings for each surface of the conversion crystals. Based on this work, we awarded the contract for the NIF KDP spin coater to be delivered in mid-1998.

Three diffractive optic elements are required for the NIF design. A color separation grating (CSG) is used to separate the residual first and second harmonic from the third harmonic energy exiting the KDP crystals. A beam sampling grating (BSG) steers a small fraction of the beam entering the final optics package, about 0.3%, into a calorimeter for diagnostics. Finally, a kinoform phase plate (KPP) homogenizes the beam and shapes it into a super-Gaussian at the target focal plane.

In 1997, we fabricated ten KPPs for Nova on debris shields larger than the NIF diffractive optics plate. These KPPs focused about 93% of the 3ω energy into a $400-\times 260$ -µm-diam spot, as compared with the NIF specification of 95% into a 1000- \times 500- μ m spot. We will fabricate a full-size NIF prototype KPP in 1998 for tests on Beamlet. There are advantages in utilizing continuous contour phase plates (CPPs) rather than KPPs on the NIF. The primary advantage comes from the use of single-step ion etching of a continuous contour gray-scale mask rather than the four-mask process used to etch the NIF baseline KPP. This simpler process could reduce the manufacturing cost. However, this approach requires the development of a large-ion etch capability with good uniformity over the full NIF aperture. To demonstrate the feasibility of this approach, we fabricated a 15-cm CPP using reactive ion-beam etching that delivered 97% of the light into a NIF-sized target spot.

We also fabricated and characterized the first NIF-size CSGs in 1997. The full-sized CSGs had excellent performance equivalent to the subscale parts demonstrated in 1996. Prior to sol-gel AR coating, the gratings transmitted 90% of 3 ω light in the zeroth order. The blocking at 1 ω and 2 ω exceeded expectations with transmissions of <1%. Fabrication of the full-scale NIF prototype uncovered a problem with AR coating. We have demonstrated that the physical geometry of the CSG is incompatible with conventional sol-gel dipcoating. In FY98, we will field a CSG prototype on Beamlet without an AR coating on the grating surface while evaluating alternative AR coatings, including spincoated sol gel and physical vapor-deposited coatings.

We have also demonstrated the lithographic process to produce full-aperture BSGs with focusing power. These gratings are made holographically, by exposing a photoresist-coated substrate to two coherent, spherically propagating laser beams—one that simulates the NIF main beam going to target focus and another equal-intensity beam that simulates the sampling beam going to focus at the calorimeter. The distances, angles, and orientations of the target focus, diffractive optic plate, and calorimeter focus are laid out on the exposure system exactly as on a NIF beamline, except that a wavelength correction is required due to the fact that our exposure laser operates at 413 nm, while the NIF third harmonic is 351 nm. The two writing beams illuminating the resist-coated substrate set up a series of interference fringes that imprint a latent grating in the resist layer. Development of this pattern results in a photoresist grating which, if properly constructed, provides a mask with which to transfer-etch this pattern into the fused silica substrate by wet hydrofluoric acid etching. This grating, when "played back" by illuminating the optic with a NIF 3ω beam going to target focus, sends off a portion of laser to the calorimeter focus at a location given by the geometry of the beam used to create it, corrected for the playback wavelength. The amount of energy sent to the calorimeter is determined to leading order by the depth of the etched grating grooves. To successfully manufacture this grating, the photoresist grating mask must be cleared to the substrate (to allow acid contact to the fused silica in between) and must have the same duty cycle (ratio of resist grating linewidth to period) across the part to assure spatial diffraction uniformity. Controlling the writing beam balance, spatial uniformity, and fringe stability during exposure are the most difficult process steps. We successfully demonstrated uniform writing of a full-size resist grating mask to illuminate a diagnostic plane 1.5 m away and to the side of the beam. In FY98, we will demonstrate a full-aperture wet-etched BSG at NIF geometry.

National Ignition Facility Project

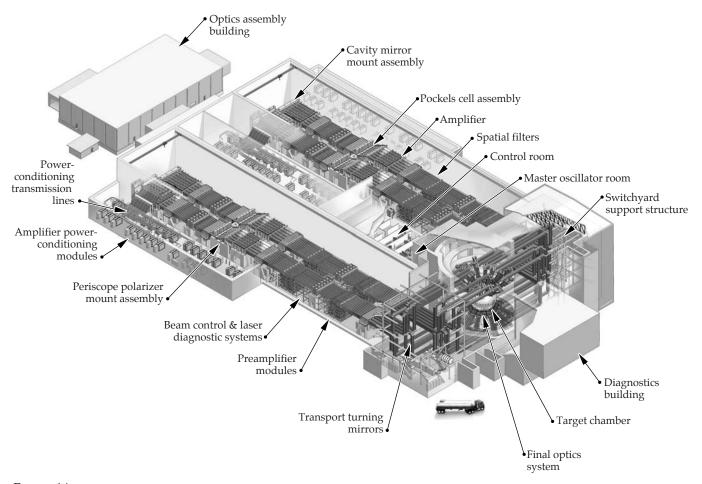
The National Ignition Facility (NIF) Project has made significant progress since completing its Title I design in October of 1996. The NIF is the largest and most complex laser project of its kind and the most challenging laser–target interaction system ever constructed. With a primary requirement to deliver 1.8 million joules (MJ) of ultraviolet laser energy at a peak power of 500 trillion watts (TW), the NIF will exceed the Nova laser at LLNL and the OMEGA laser at UR/LLE, currently the world's largest ICF experimental tools, by factors of 40 in energy and over 10 in peak power.

The NIF is a key component of DOE's science-based Stockpile Stewardship Program. High-energy-density science spans the gamut from weapons physics studies to planetary geoscience and astrophysics. Researchers from all over the globe have begun to plan NIF experiments. They can learn about the NIF and its progress by accessing the informational Web pages provided on the Internet (http://lasers.llnl.gov). Figure 14 shows an isometric

CAD drawing of the NIF Title I (preliminary) design, described in detail in the *ICF Quarterly Report* for July–September 1997. The Project received the fiscal year (FY)97 and FY98 funding (\$191.1 million and \$229.1 million respectively) required to maintain its Title I baseline. Together with the DOE Secretarial level National Environmental Policy Act Record of Decision/LLNL site selection on December 19, 1996, and Critical Decision 3 (approval to begin construction) on March 7, 1997, the Project is positioned to produce first bundle operations by the end of FY01 and be complete by the end of FY03.

By the end of FY97, we had filled NIF Project management and staff positions to the planned levels. An engineering and support team with almost 400 members, drawn from LLNL, SNL, LANL, and UR/LLE, was approximately halfway through Title II (final) design by year's end, with nearly 90% of all requirements and interfaces under configuration control. In addition, we had completed the NIF structural design to 100% levels in many areas, and excavation was almost complete with concrete being poured, as the photograph in Figure 15 illustrates. We had awarded five of the eight Conventional Facilities construction packages for site preparation, site excavation, target building mat and laser bay foundations, laser building shell, and the Optics Assembly Building. The NIF will occupy a building that is 704 feet long, 403 feet wide, and 85 feet tall, about the size of a football stadium (e.g., the NIF would just fit inside the New Orleans Superdome). The NIF is twice as tall, long, and wide as LLNL's Nova facility.

In 1997, we placed major Project facilitization contracts with commercial vendors (i.e., for finishing of flats, mirrors, lenses, laser slabs, KDP crystals, and fused silica production) to ensure an adequate optics production capability that meets the NIF cost goals. The NIF laser will contain 33,000 square feet (three-quarters of an acre) of highly polished precision optics, such as glass laser amplifier slabs, lenses, mirrors, and crystals. This is more than 40 times the total precision optical surface area in the Keck telescope in Hawaii, the largest telescope in the world. We also implemented new slab production technologies based on continuous pour of laser glass to meet NIF cost goals (almost a 20-fold improvement compared to Nova). By year's end, we had development runs under way addressing the many production issues that needed to be resolved to produce optical components of the quality required by NIF specifications. We prepared far more precise optical component drawings, which had to conform to the ISO10110 international standard, than earlier laser projects required. The volume of precision optics required for the NIF challenges the existing capacity of skilled opticians working inside the United States. In this era of fiber optics communication, skilled optics fabricators are already much in demand. Consequently, the NIF's optical procurement group initiated an opticians training program at Monroe Community College in Rochester, New York.



 $FIGURE\ 14.\ NIF\ Title\ I\ design. \qquad (40-00-0996-2100Apb04).$

The NIF's Title II design depends on the production of thousands of interdependent, accurate computer-aided designs, beginning with laser system simulations, which combine specialized software packages developed at LLNL, such as PROP92, with commercial software packages such as IDL, GLAD, Code V, and ASAP. We main-



FIGURE 15. Excavation and forms for the NIF target area at year's end. (40-60-1197-2342#1pb01).

tained the technical basis of the NIF design and updated it throughout the year as improved component information became available. In addition to NIF Council reviews, NIF 65% Title II Reviews, and ICF Programmatic reviews, the NIF Project Scientist established a Scientific Panel to oversee the progress of NIF technology development. ICF Program restructuring early this year combined NIF Special Equipment and NIF Development into a single organization to complete the core science and technology activities and transition into the final design phase of this Project. This resulted in significant progress on the Optical Pulse Generation System, or OPG; the accelerated activation of the NIF Amplifier Laboratory, AMPLAB; and the beginning of prototype testing.

Concurrent with these technology development activities, we reviewed and updated the documents that provide a hierarchy of the NIF design requirements, including *System Design Requirements* and the laser system design/performance baseline. Change Control boards, established last year, meet regularly each week. NIF Engineering Services employs over 200 advanced workstations to generate the thousands of detailed drawings required. As

these (mostly ProE and AutoCAD) drawings are completed, they pass through a sign-off and checking process before being placed under change control. We selected and implemented the commercial Sherpa Product Data Management system to provide a project-wide centralized document, engineering drawing, and configuration control capability. We also conducted regular cost and schedule reviews to track progress. The NIF Associate Project Engineer for Special Equipment held weekly engineering status meetings to assure that each System Engineering group was kept up to date on all aspects of the NIF Project. Monthly and quarterly progress reports were also prepared and distributed.

Throughout 1997, we utilized project controls developed and implemented the previous year, including the NIF Project Control Manual, the Configuration Management Plan, the Integrated Project Schedule, Cost Account Plans, and the DOE-approved Quality Assurance Plan. The NIF underwent a full DOE Safety Management Evaluation late in the year and was judged to be a model project. During the excavation of the NIF site, for example, buried capacitors leaking detectable levels of polychlorinated biphenyls were uncovered. Safety response and cleanup teams were prompt and professional in dealing with each hazard. As a result, construction delays were minimized.

At the end of FY97, the NIF Project was on schedule and on budget, and its staff was confident in its commitment to meet all of the NIF's requirements.

Inertial Fusion Energy/New Technology Applications

Inertial Fusion Energy

ICF science and technology developed as part of the DP mission goals, in conjunction with Laboratory Directed Research and Development (LDRD) and research sponsored by the DOE Office of Fusion Energy Science, support the development of inertial fusion energy (IFE) as a possible long-range energy source. Work at Livermore supports the development of an IFE driver based on both a heavy-ion induction accelerator (HIF) and a diode-pumped solid-state laser (DPSSL).

In HIF research, LLNL has a broad-spectrum program, including heavy-ion target design, systems analysis of heavy-ion drivers and power plant chambers, and experiments with space-charge-dominated heavy-ion beams, with supporting theory and simulation of beam physics for present and future accelerators. The LLNL work on beam theory supports experiments both at LLNL and at Lawrence Berkeley National Laboratory (LBNL). Over the last year, we completed a high-gain heavy-ion target design,

modeled a multibeam linac driver meeting the requirements for that target, conducted LDRD experiments in beam bending through 90 degrees, and performed 3D beam particle simulations for those experiments.

We completed integrated calculations for a distributed radiator heavy-ion target design. This target ignited and produced 390 to 430 MJ of yield when driven with 5.8 to 6.5 MJ of 3-4 GeV Pb ions. The target has cylindrical symmetry with disk endplates. The ions uniformly illuminate these endplates in a 5-mm-radius spot. We used low-density hohlraum walls in approximate pressure balance with internal low-Z fill materials. Radiation symmetry was determined by the position of the radiator materials and particle ranges, with early time pressure symmetry influenced by radiation shims. ¹² Future work will consider higher ion range, scaling to lower input energy and/or to lower beam power and more realistic beam-focusing geometries.

A systems model for a multibeam linac driver was completed to study cost and design optimizations for drivers capable of meeting the requirements of the target described above. The model integrates all accelerator subsystems from the ion source to the target, including drift-pulse compression and final focusing, using analytic models for beam physics and engineering constraints. Modifications of the model to treat recirculators, solenoid linacs, and higher ion charge states are in progress to permit future comparisons of different accelerator architectures.

We have completed the second year of a three-year LDRD experiment on heavy-ion beam bending and control, jointly supported by the Lasers, Physics, and Engineering directorates. Our goal is to address the critical scientific and technical challenges of bending, steering, and pulse-shape control of a space-charge-dominated heavy-ion beam. At present, experiments have been conducted through 45 degrees of bend; experiments on a 90-degree bend with five production modulators have begun.

LLNL's leading candidate for a laser driver for IFE is based on a DPSSL. The Mercury laser, which is an LDRD strategic initiative project, is intended to be 10% efficient, provide 100 J of energy in nanosecond pulses, and operate at 10 Hz. The critical technologies upon which Mercury is based are diode array pumps (instead of the flashlamps used in the NIF), Yb:S-FAP crystals (that replace the Nd:glass used in the NIF), and gas-cooled laser heads.

Figure 16 contains pictures of the key technologies of Mercury that are under development—a completed 40-bar laser diode array and a full-diameter Yb:S-FAP laser crystal. Figure 17 is a sketch of the laser architecture that will be used. Each diode array is referred to as a "tile," and 40 tiles will be needed for each of the four 160-kW peak-power diode arrays that will be deployed in



FIGURE 16. Photograph of an Yb:S-FAP laser crystal and laser diode array tile. (70-17-0695-1699Cpb01)

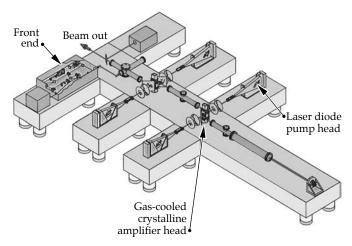


FIGURE 17. Schematic design of the Mercury laser system. (70-00-0497-0657pb01)

Mercury. Most aspects of the heatsink and fabrication technology of the diode arrays have been developed, and we are currently finalizing the structure of the epitaxially grown semiconductor wafers that are processed into the laser bars. We have successfully grown laser crystals that are free of cracks and "smoke," and are in the process of eliminating the core defects that collect near the center of the boule. The design of the laser system has been modeled and optimized by including technical considerations as diverse as the diode spectral chirp and power sag caused by heating and diode array light delivery to the

laser crystal limited by the measured array brightness, pump absorption, extraction efficiency with optical losses, damage and B-integral limits, thermal distortions, and required helium flow conditions. The system has been modeled to a level of detail to have confidence that we will be able to generate 100 J at 10 Hz with 10% efficiency. Beyond Mercury, we envision a sequence of the DPSSLs—Venus (1 kJ), Terra (15 kJ), and Helios (MJ-scale), that could enable improved means of meeting Stockpile Stewardship objectives and ultimately a fusion energy power plant. Importantly, Mercury and subsequent lasers will also have important uses in developing the target technologies needed for IFE.

New Technology Applications

LLNL has a history of initiating research on a broad range of applications of technology developed in the ICF Program. These applications include high-average-power solid-state lasers, Extreme Ultraviolet Lithography (EUVL), and Micropower Impulse Radar (MIR), which have grown into independent programs within the Laser Directorate at LLNL.

A major initiative of the LS&T Program over the past year has been to develop high-average-power femtosecond (fs) lasers for use in the SSP. Thus, technology that grew out of the Petawatt projects has returned to the point in which a 12-W, 100-fs laser-cutting workstation (LCWS) is now being developed for the Y12 plant. The LCWS, being developed jointly with the Weapons Program, will be delivered to Y12 in 1998. LS&T laser technology has also been applied to the DOE-sponsored Caliope Project for remote sensing of chemicals associated with nuclear materials proliferation. A rapidly tunable DPSSL-based optical parametric oscillator operating in the moderate infrared range was tested at the Nevada Test Site in 1997 and proven to detect small concentrations of chemicals at relevant distances. Multishot averaging of atmospheric fluctuations was proven to be quite effective.

High-power laser spin-offs from ICF have also been valuable to DOE. LS&T is now completing the Advanced Imaging Testbed (AIT) laser based on Zig-Zag slab technology, which produces exceptionally coherent 50-J 2 ω beams operating at 3 Hz. The AIT laser is scheduled for delivery to the Startive Optical Range at the Philips Laboratory in 1998. In 1997, LS&T also began the development of a heat capacity laser for tactical missile defense planned for use at the High Energy Laser Strategic Test Facility under Army support. In addition, LS&T has been working with an aerospace partner on DPSSL-based illuminators for use with the Airborne Laser, a NIF-scale project of national importance under Air Force sponsorship.

A recent thrust has been the development of applications to medicine including: (1) modeling laser–tissue

interactions, (2) establishing a medical photonics laboratory for developing a host of new medical technologies, and (3) developing user-defined laser diodes and DPSSLs for medical procedures (e.g., port-wine stain removal, tattoo removal, and laser surgery).

The application of computer modeling to medicine uses the LATIS computer program. LATIS is a time-dependent, two-dimensional program. It considers four categories of physical processes and their nonlinear coupling: laser propagation, thermal response, material response, and hydrodynamical response. Because of similarities to ICF modeling in the physical processes, the mathematical equations, and the numerical methods to solve the equations, we have been able to build on the 25 years of experience in ICF modeling to develop LATIS.

One of the main differences between medicine and fusion is the temperature scale (≤1 eV vs several KeV). Because of this and the different materials involved, we have had to obtain special data such as opacity, conductivity, equation-of-state, and chemical reaction rates.

During the last year, the modeling project has made several important contributions. In laser tissue welding, we concluded that water diffusion and evaporation play an important role in setting the tissue surface temperature. We also modeled the temperature profiles achieved in animal vessel repair experiments done in collaboration with University of California at Los Angeles Medical School. In particular, we studied the effect of using a feedback control system in these experiments. The models provided an explanation of the difference in weld quality achieved with and without feedback control.

We have applied LATIS to the study of laser-generated vapor bubbles as part of a project to develop a device for breaking up blood clots that cause strokes. We found that although bubbles appear rather spherical in experimental photographs, 1D spherical simulations overestimated the size and duration of the bubbles by about 50%. We developed a new rezoning method to enable the creation of 2D simulations over the long time period of the bubble expansion and collapse. We found very good agreement between the 2D results and experiment. Such simulations have been used to help design a device that is now in animal trials by an industrial partner.

We also developed a model for laser absorption in the multiphoton-initiated plasma regime and applied it to simulations of ultra-short-pulse high-precision tissue ablation. In comparison to experimental measurements of the ablation of dental enamel, we have found good agreement in the ablation threshold and the sharp peak in ablation efficiency just above threshold. The model including only direct vaporization of the enamel underpredicts the amount of material removed. We explored alternate mechanisms, such as melting and pressure-induced material failure and believe that they may play an important role in ultrashort pulse ablation.

We have found many mutual benefits between laser medicine and ICF modeling. We found it quite effective to build on the ICF experience in first developing the basic laser medicine capability. There has also been a spinback from our medicine experience to ICF. In particular, errors in laser photon Monte-Carlo tracking have been found and corrected. The material strength and failure packages developed to model tissue spallation have been recently applied to design and analyze RT experiments. We also expect that the rezoning scheme recently developed for the stroke treatment project will find use in ICF simulations.

Program Resources and Facilities

Resources

In FY 1997, financial resources for the LLNL ICF Program totaled \$84.5 million in DOE operating funds and \$2.1 million in DOE capital equipment allocations. At LLNL, the NIF Project managed \$59.2 million in new DOE operating funds and \$131.9 million in new construction funds for FY 1997. The average LLNL full-time employee equivalent count over the year was 255.3 for the ICF Program and 264.9 for the NIF Project. Supple-mental contract labor personnel were used in clerical, design, and engineering positions, as well as for Nova operators. The ICF Program employed approximately 53.0 supplemental labor personnel, and the NIF Project employed approximately 51.2 supplemental labor personnel in FY 1997.

Figure 18 shows the resources available to the ICF Program over the past 16 years and compares the operating funds provided by DOE in then-year dollars vs the same funding discounted to reflect 1982 dollars. The figure illustrates that the real purchasing power for DOE funding, as related to FY 1982, has remained fairly constant and is expected to remain so in FY 1998. These resources enabled the ICF Program to continue its support of research and development of high-energy-density physics, laser component development, optics technology development, and optics pilot production.

Table 1 illustrates the NIF Project national funding profile as provided during the FY 1999 Field Budget Submission to DOE. As of FY 1997, 22.5% of the total project funding had been obligated by DOE.

The resources provided to the NIF Project in FY 1997 provided for the start of facility construction, including site preparation and extensive site excavation, as well as for the continuation of final design activities across the Project. Major contracts were awarded for the facilitization of optics manufacturers and supply of structural steel.

FIGURE 18. Resources available to the ICF Program over the past 16 years compared with operating funds provided by DOE in then-year dollars. (05-00-0598-1131pb01)

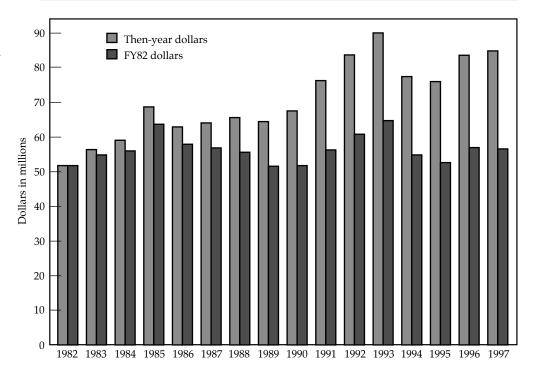


TABLE 1. NIF Project national funding profile.								
Funding type (\$M)	Prior years	FY97	FY98	FY99	FY00	FY01	FY02	FY03
Operating (Other project costs)	41.8	59.2	31.3	6.8	10.0	1.8	1.4	0.9
Construction (Line item)	37.4	131.9	197.8	284.2	248.1	74.1	65.0	7.2

Facilities

The 1997 facilities activities addressed both support of ongoing operations and buildup of the Title II engineering staff and the beginning of NIF construction. The major activities included: (1) maintaining and providing selected upgrades to the existing Nova, Beamlet, AMPLAB, and development facilities to support demanding experimental schedules; (2) providing space and infrastructure such as networking to accommodate the increased engineering staff for the NIF Title II design; (3) completing use agreements and acquiring construction and laydown areas on the LLNL site in preparation for the beginning of NIF construction; (4) completing a first round of detailed planning for transitioning existing Nova/Beamlet-centered facilities to the NIF and beginning designs in support of this transition.

The ICF Program comprises 54 facilities including laboratories, offices, and support areas totaling

638,000 gross sq ft. Figure 19 shows the locations of these ICF facilities within the Laser Programs and the Laboratory.

Specific activities and accomplishments are described below:

- Building and support system (e.g., low-conductivity water) maintenance were reviewed, prioritized, and updated or corrected as necessary in the key on-line Nova, Beamlet, AMPLAB, and development facilities to assure continuing a high level of experimental operations.
- Several upgrades and modifications to key laboratory- and building-related equipment totaling \$2.7M were completed. These included a B481 power feeder upgrade; B298 utility and air-conditioning upgrade; B392 heating, ventilating, and air-conditioning upgrade; and various laboratory, office, and support area modifications.

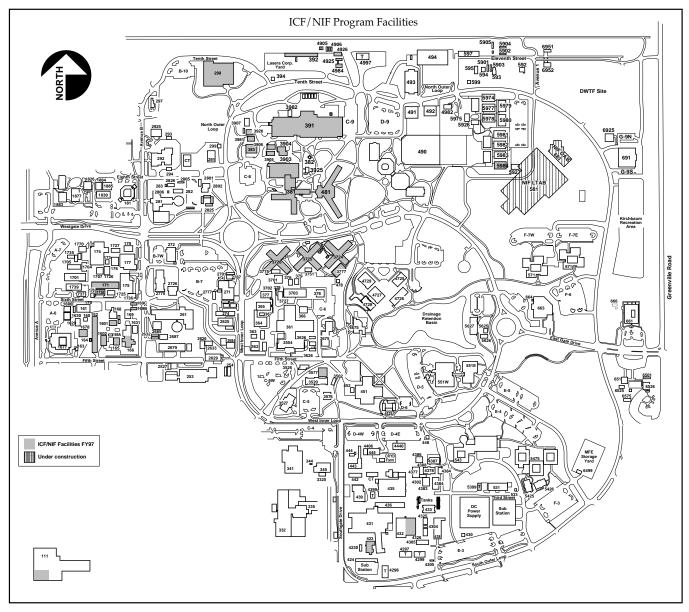


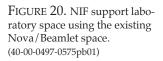
Figure 19. Locations of ICF Program facilities at LLNL. (05-00-0497-0547pb02)

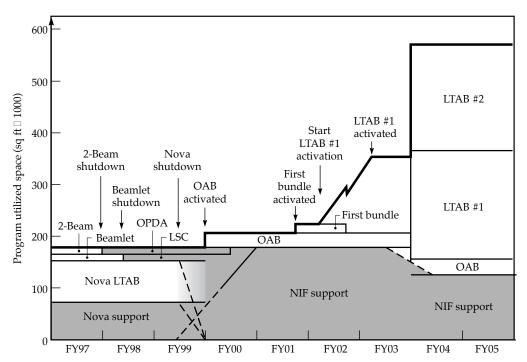
- One of the outcomes of having the Laboratory selected as the official site for the NIF was the increased need to provide additional access to the NIF staff. In support of this need, B481 was converted from a limited (Q) to an administrative controlled (P) status. Although the security level was lowered, proprietary activities within the building still require continued alarm and access control. This access is controlled through the existing CAIN booths at the building entrances. All red badge employees that need access must contact one of the Program Area Access Requesters for access privileges.
- The continuing need for classified meetings for integrating the numerous science, engineering,

- technical, and administrative activities within the ICF Program and the NIF Project led to conversion of the B381 Auditorium to a permanent limited (Q) status to provide additional capability for large classified briefings.
- The growth in office/design space (~200 spaces) for the NIF engineering teams was largely accommodated through the use of existing facilities. Temporary lease arrangements with organizations outside the program were arranged for the remaining space. Collocation of engineers/designers primarily within the core ICF/NIF facilities maximized worker efficiency.
- A space utilization program was implemented. Approximately 15% of the total ~200

- spaces required for growth in the NIF engineering teams came from improved space utilization, thereby avoiding substantial spacerelated expenses. Additional areas of increased utilization have been identified and are being implemented.
- Agreements (~20) between the ICF Program and various organizations including LLNL, DOE, and the University of California pertaining to building and land use (e.g., construction areas) were completed in preparation for the beginning of NIF construction. This documentation was catalogued and entered into the Quality Assurance library.
- The support facilities needed for NIF buildup and operations were estimated based on the NIF design, Nova/Beamlet operational data, and detailed inputs from the special equipment engineering staff. Existing space use was reviewed, areas were selected as conversion candidates, and cost estimates were prepared. The support laboratory space for the ICF/NIF Program will be approximately double that of the ICF/Nova Program by using existing Nova/Beamlet space (Figure 20).
- In support of the facility transition effort, a number of feasibility and conceptual design and cost studies were completed addressing conversion or upgrade of existing space to that required for the NIF.
- The ICF Program is completing its current use of the west end of Building 391 as the Two-Beam

- area. Following analysis and review, this area was designated as the Optics Processing Development Area (OPDA) and will be modified as a laboratory to develop techniques for the cleaning and coating of large-aperture optics. Planning for dismantling of the existing Two-Beam special equipment started, and design for conversion to the OPDA is nearly complete. Construction is scheduled to begin second quarter FY98.
- A preliminary design was completed for conversion of a portion of the Beamlet Hi-bay to a facility for construction of the NIF amplifier frame assembly units following Beamlet shutdown tentatively scheduled for third quarter FY98.
- Various smaller ICF laboratories have been transitioned for use in NIF development and eventual NIF support. Overall, ~35,000 sq ft (~15%) of total ICF experimental space is now in transition.
- The NIF Project has need for ~50,000 sq ft of warehouse space starting third quarter FY98 and for the project duration to accommodate special equipment construction. The availability of on-site space was evaluated with the Laboratory, and no available on-site space meets the requirements. Procurement was requested to begin a survey of off-site warehouse space for cost and availability with preference given to that in close proximity to the Laboratory site.
- Planning has started for the next phase in transitioning office/designer space following completion of the NIF Title II design.





Environment, Safety, and Health (ES&H)

A number of steps were taken in FY97 to improve the ES&H Program to ensure continuing safety of the ongoing operations and to be consistent with an increase in level of activity resulting from the selection of the Laboratory as the NIF site. This selection led to the beginning of site preparation and the beginning of construction. A continuing strong self-assessment program provides the basis for evaluation and improvement.

The ICF ES&H activities encompass 15 major facilities located throughout LLNL with 75 individual laboratories and experimental areas. There are currently 44 Operational Safety Procedures (OSPs) and 3 Facility Safety Procedures (FSPs) pertaining to program operations. Specific activities and accomplishments include:

- A Safety Advisory Group consisting of program personnel from a range of disciplines was reinstated. This group, reporting to the Deputy Associate Director for ICF/NIF/High-Energy-Density Experimental Science, provides an independent evaluation of safety in the design, construction, operation, and maintenance of existing NIF laser and laser-related systems.
- The program ES&H team now includes a Program Laser Safety Officer. This individual provides expertise and support on evaluation and control of laser hazards in all program elements consistent with the applicable laser safety standard ANSI Z136.1. Included is responsibility for installation, checkout, and maintenance of all safety interlocks.
- A Red Team review of the 44 OSPs and 3 FSPs was completed to determine the adequacy of the OSP/FSP and the consistency of the OSP/FSP and the work being performed. Included was a Laboratory walkthrough by the review team with the Responsible Individuals (RIs). The findings and comments were reviewed and documented. Laboratory specific deficiencies were corrected by the RIs. General OSP deficiencies, most of which are procedural, are being corrected as the OSPs are reviewed and approved.
- RI roles/responsibilities information was updated, and mandatory training for all RIs was completed and is current. The training included a component on Integrated Safety Management (ISM).
- Training matrices have been added to all OSPs/FSPs for improved tracking of training. Classes are scheduled in coordination with the Laser Assurance Training Coordinator. Training compliance was reviewed and improvements were made as required.

- The 1997 self-assessment program was completed as scheduled and all laboratories and facilities are current. A total of 256 laboratories and experimental areas were assessed with 297 noted deficiencies. A review of the data shows a close resemblance to previous years in both number and types of findings with the most hits assigned to the "general" category (e.g., exit signs, locker labels, seismic restraints). The assessment identified no imminent hazards, and corrections are under way. DefTrack is used to track completion of these deficiencies and analyze trends.
- The LLNL/DOE Work Smart Standards process was supported with work/hazard identification on selected facilities. Standards verification is under way consistent with the LLNL/DOE schedule.
- Facility deactivation has been formalized with development of a Shutdown Surveillance and Maintenance Plan for the Two-Beam area in B391. This plan will address the removal of special equipment by program personnel following a Two-Beam shutdown scheduled for first quarter FY98. This plan will serve as a model for the future Beamlet and Nova close-out and overall facility transition safety management.
- An activity authorization section was added to all OSPs. This section serves as a reminder for the Approving Individual that he/she is responsible for pre-start and readiness requirements as outlined in the LLNL Health and Safety Manual.
- A start-up procedure has been developed and implemented for all new and revised experimental activities. The procedure is used by the RI in conjunction with ES&H Assurances and Hazards Control to ensure that applicable ES&H requirements have been reviewed and integrated into the activity before the start-up is authorized. The procedure includes program management's approval to begin the new or revised activity.
- ES&H roles and responsibilities information was updated and communicated to all program personnel. Included were revisions of the program organization charts showing recent changes. Emphasized are the organizational elements involved in managing and implementing ES&H in the Program, including line management, ES&H support, coordination and oversight, and ES&H technical support. Also identified are the OSP Approvers, RIs, the associated OSPs/FSPs, and program cost centers.
- The NIF Project Management System is documented in the Project Execution Plan, Project

- Management Descriptions, Project Control Manual, Integrated Project Schedule, Cost Account Plans, Quality Assurance Program Plan, and supporting documents. The management system was evaluated by the DOE OAK and found to be complete and operational.
- The NIF primary criteria and functional requirements were developed according to the DOE process and Work Smart Standards. These criteria have been approved by DOE and incorporated into the contract between DOE and the University of California.
- The NIF Specific Analysis is Appendix I of the *Programmatic Environmental Impact Statement* (PEIS) for the SSP. This document provides the detailed environmental impacts for the construction and operation of the NIF. The *Mitigation Action Plan* issued in February 1997 presents the activities needed to mitigate the impacts described in the PEIS. A full set of environmental permits were applied for and approved (e.g., Storm Water Pollution Prevention Plan, etc.) for the construction of the NIF and support facilities (e.g., B391W).
- The NIF *Preliminary Safety Analysis Report* was approved in October 1996, and then as design evolved, a set of amendments evaluating these new features and a set of audits of the final Title II design were conducted to ensure that safety commitments were met. These activities form the basis for the *Final Safety Analysis Report* (FSAR) that will be started in FY98.
- The NIF Construction Safety Program was approved, and then subtier safety plans were prepared. Training was conducted, and the safety plan implemented at the NIF construction site. The DOE Safety Management Evaluation review of LLNL included the review of construction safety. The NIF was thoroughly reviewed, and the resulting conclusion of the

- evaluation report was that "...NIF safety management is a model of integrated safety management with respect to construction."
- The NIF Construction Safety Team continues their weekly meetings to coordinate site construction, safety audits, and environmental issues for NIF construction. The NIF Environmental and Safety Working Group continued their biweekly meetings to coordinate ES&H documents and evaluations like the NIF Risk Management Plan, Waste Minimization and Pollution Prevention Plan, and the FSAR.
- Quality Surveillances and Audits have been conducted for a broad range of Project activities (e.g., design, configuration control, concrete work, etc.). These reviews are all documented, and any action items are tracked to completion in the Project tracking system.
- A safety feature audit of B39 W, Optics Development Facility, was completed. All required safety features for facilities were found to be present in the design modifications and the remaining parts of B391.

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NIF GLOSSARY

- **adaptive optics** Optical components whose shape can be actively changed to compensate for optical wavefront distortions. NIF uses thin, electrically controlled, deformable mirrors for this function.
- amplifier slab As used in NIF, a neodymium-doped phosphate glass slab that is set in the beam at Brewster's angle and pumped by xenon-filled flash-lamps. The light from these flashlamps excites the neodymium ions to a higher energy state that leads to amplification of light beams at a small range of wavelengths around 1053 nm.
- **amplitude modulation** Changing the amplitude of a signal without affecting its phase.
- anode The positive electrode of an electronic device.
 apodizer A variable-transmission filter that puts a smoothly varying irradiance profile on the edge of a beam in order to suppress diffractive ripples
- architectural design The process of defining a collection of hardware and/or software components, their functions, interfaces, and key characteristics to establish a framework for system development.
- architecture The logical and physical structure of a system forged by all the strategic and tactical decisions applied during development. Software architecture deals with abstraction, with decomposition and composition, with style and esthetics.
- **asynchronous transfer mode network (ATM)** A cell-based switched network capable of carrying time-critical data such as video.
- **backlighter/backlighting** Many NIF experiments will require that some of the beams be used to generate a source of x rays that is used to photograph the main experiment. This source is usually called a "backlighter."
- **beam dump** An optical component that disposes of an unwanted beam safely.
- **birefringence** A material has this property if its index of refraction differs for different light polarizations.

- An input light beam is then separated into two beams that take slightly different paths through the material.
- **blast shield** As used in NIF, a glass shield that protects amplifier slabs from contamination generated by flashlamps.
- **borosilicate float glass** A high-quality window glass manufactured by floating molten glass on a liquid metal support.
- **boule** An "as-grown" synthetic crystal before finishing. **Brewster's angle** A beam of light incident on a slab of optical glass at this angle (about 57° to the surface normal) has zero reflection for one of the polarization components of the beam.
- Brillouin scattering Stimulated Brillouin scattering (SBS) is an interaction between light and sound waves in a material that leads to the growth of the sound wave and a second, scattered light wave. It is an undesirable effect in large lasers.
- **bundle** A NIF "bundle" is an array of beams stacked four high and two across. The bundle is the basic building block of the laser system.
- **calorimeter** A device used for measuring the energy of a laser pulse by measuring the temperature rise of an absorber.
- **canister** A protective cover "box" in which a line-replaceable unit (LRU) is placed for transport to a desired location.
- cathode The negative electrode of an electronic device.cavity spatial filter (CSF) The spatial filter within the NIF main laser multipass cavity.
- **centering** Positioning a beam in the center of an optical aperture when the beam is at full size (near field). See pointing.
- **charge-coupled device (CCD)** A type of image sensor used in TV cameras.
- **class** In software parlance, a class is a set of objects that share a common structure and a common

- behavior. Typically classes are static; their existence, semantics, and relationships are fixed prior to the execution of a program.
- **clear aperture** That portion of the aperture of an optical component that we allow the laser beam to occupy. See hard aperture.
- **client** An object acts as a client in an interaction with another object (the server) if it initiates the interaction.
- client/server computing Client/server computing encompasses a decentralized architecture that enables end users to gain access to information transparently within a multivendor environment of heterogeneous hardware and software platforms.
- **cluster** A NIF "cluster" is an assembly of six bundles. The NIF laser contains four clusters, each containing 48 beams.
- color separation grating (CSG) As used on NIF, a kinoform that transmits 3ω with no deflection, but diffracts 1ω and 2ω away from the target.
- common object request broker architecture (CORBA) An *ad hoc* industry standard for software objects that communicate across processors in a network.
- **configuration** A framework that is a collection of classes that all subsystems use to maintain the complete as-built description of the devices that they control.
- dark-field imaging See schlieren technique.
- **datum** A precise position reference.
- diffractive optic See kinoform.
- **doubler** A frequency conversion crystal that converts
- **event-based** A system organizing concept (from the software programmer's point of view) wherein an application program is notified of outside occurrences by events.
- **far field** A position in an optical train that is very far from an image. In NIF, the far fields occur at the focal planes of lenses in the spatial filters or the target chamber.
- **Faraday rotator** An optical device that uses Faraday's magneto-optic effect to rotate the plane of polarization of a light beam.
- filamentation See nonlinear index.
- **final optics assembly (FOA)** A NIF assembly that includes the target chamber vacuum window, final optics cell, diffractive optics plate, debris shield, and some laser diagnostics.
- **final optics cell (FOC)** The final optics cell is an assembly that holds and positions the two frequency conversion crystals and the target focus lens.
- **first wall** The inside wall of the NIF target chamber. It must be highly resistant to x rays, other target radiation and debris, and laser light.
- **flashlamp** As used in NIF, a xenon-filled quartz gas-discharge lamp that is used to pump amplifier slabs.
- **fluence** The energy per unit area (generally J/cm²) in a beam of light.

- **framework** A large-scale software building block. A framework provides architectural guidance by partitioning the design into abstract classes and defining their responsibilities and collaborations.
- **freeboard** The difference between the maximum expected aperture occupied by a beam and the actual clear aperture of an optical component.
- **Fresnel lens** A thin lens constructed with stepped setbacks so as to have the optical properties of a much thicker lens; also an example of a "kinoform."
- **front-end processor (FEP)** The low-level computer that implements device control.
- **fused silica** A glassy, noncrystalline form of quartz (SiO₂). The fused silica used in NIF is usually a high-purity form that is manufactured by chemical vapor deposition (CVD).
- **Gaussian beam** The beam generated by a laser that is forced to operate in a single, lowest-order mode.
- ghost beam, ghost focus, ghost reflection Optical components that transmit laser beams in NIF are antireflection coated, but these coatings are never perfect so some very small laser energy is reflected at each of these surfaces. Although the energy in these beams is small, it is important to manage carefully where it goes in the system. If these beams come to a focus, for example, they can easily reach fluences that cause severe damage to components located near that focus.
- half-wave plate A thin section of a birefringent crystal cut so that it rotates the polarization of light passing through it when the crystal is rotated around its optical axis.
- hard aperture The aperture set by the mechanical mounting hardware for an optical component. The beam must not strike this hardware, consequently the hard aperture is larger than the clear aperture.
- Hartmann sensor, Hartmann wavefront sensor A sensor that uses an array of small lenses to measure local wavefront tilts on a beam. The lenses generate an array of far-field spots on a charge-coupled device (CCD) camera, and image-processing software uses the positions of these spots to reconstruct the wavefront of the beam.
- **HEPA** High-efficiency particulate air. A type of air filter using paper elements that is commonly used in clean rooms.
- **hierarchy** A ranking or ordering of abstractions where the lowest common denominator is placed at the top and from this base all other classifications arise.
- image relay An arrangement of optical components that forms a real image of a beam-defining aperture at several points ("relay image planes") through an optical system. Effective optical propagation distances are reset to zero at each image, so an imagerelayed system has less beam modulation from diffraction than an unrelayed system.

- **injection system** A NIF system that takes the input beam from the preamplifier beam transport system (PABTS) to the pinhole plane of the transport spatial filter.
- **input sensor** A NIF system that diagnoses the output of the preamplifier module (PAM) before it is injected into the main laser cavity.
- **Integrated Computer Control System (ICCS)** The system of computers and software which control NIF and stores information about its history and operation.
- integrated optics module (IOM) An assembly that holds and positions the target chamber vacuum window, final optics cell (FOC), diffractive optics plate, and debris shield for a single beam of NIF. The IOM is a line-replaceable unit. (See final optics assembly.)
- irradiance The power per unit area (generally W/cm²) in a beam of light. Sometimes called "intensity;" however, the official SI definition of intensity includes a measure of the divergence of the beam.
- KDP, KD*P Potassium dihydrogen phosphate crystal (KH₂PO₄). Thin plates of this crystal and its deuterated analog KD*P (KD₂PO₄) are used as the active optical elements in the NIF PEPC and frequency converter.
- **kinematic mount** A mount designed so that components placed on it are forced to come to rest in a very precise location.
- **kinoform** An optical component with fine phase structure that changes the phase of a beam ("diffractive optic").
- **laser entrance hole (LEH)** An aperture in a hohlraum target through which the laser beam enters the hohlraum.
- line-replaceable unit (LRU) A self-contained package, containing multiple laser components, that can be assembled and tested off-line in a clean room and then installed on the laser as a unit while preserving its highly clean and prealigned state. LRUs are installed on prealigned kinematic mounts in the NIF laser. Examples include the preamplifier module (PAM), a column of four amplifier slabs in the amplifier; a cassette of flashlamps in the amplifier; a column of four spatial filter lenses; and an integrated optics module (IOM) in the final optics assembly.
- machine history Data that are saved by the integrated computer control system (ICCS) software that are pertinent to the operation and maintenance of NIF.
- **message log** A framework that stores and retrieves text messages from many software components for the purpose of constructing an audit trail of system action.
- near field A position in an optical train that is close to an image. In NIF, these are the regions where the beam is at its full size.
- **nonlinear index, nonlinear phase shift** Optical materials have an index of refraction, which is the ratio of the speed of light in a vacuum to the speed in the optical

- material. At very high irradiance the index of refraction increases, or the speed of light is reduced in the material. Local regions of high irradiance travel more slowly, so the optical wavefront becomes concave near them. A concave wavefront is a focusing wavefront, so the local irradiance grows even larger as the diameter of the local hot spot decreases. This process amplifies any irradiance noise on the laser beam and can ultimately lead to "filamentation." In filamentation, the local region of high intensity collapses to an extremely intense spike that damages the material along a track a few microns in diameter. A few micron-sized damage tracks of this sort cause no particular harm, but a large density of them can obscure parts of the beam and can initiate further optical damage.
- object A software entity that the system can act upon.
 optical damage High laser irradiance and fluence can heat small defects in the bulk or on the surface of an optical component. These defects then explode and can cause damage (such as a pattern of small fractures) to the component. These damage sites may grow to a size that affects the laser's operation on subsequent shots, and the component must then be replaced. Components for a high-fluence laser such as the NIF must have a low density of defects and must also be kept very clean so that dirt particles that might initiate damage are very infrequent.
- optical pulse generation system (OPG) The lowenergy, small-aperture parts of the NIF laser that shape and amplify the laser pulses before they are injected into the main laser cavity.
- **output sensor** A NIF assembly that diagnoses the output beam from the laser.
- **periscope** As used in the NIF, the structure that supports the plasma-electrode Pockels cell (PEPC), polarizer, and two laser mirrors—LM2 and LM3.
- **periscope installation assembly** A type of line-replaceable unit (LRU) installation structure that requires the use of spacers to lift LRUs to the required heights for installation.
- **phase modulation** Changing the phase (or frequency) of a signal while the amplitude is held constant.
- pinhole As used in NIF, an aperture in the focal plane of a spatial filter. The main laser pulse goes through the aperture, while stray light and high-spatial-frequency noise hit the edge of the aperture and are removed from the beam.
- plasma-electrode Pockels cell (PEPC) A Pockels cell that uses tenuous helium plasmas as electrodes to apply a voltage to the active element.
- **plenum** A chamber used to connect a gas supply or a vacuum pump to other volumes that require these services.
- **Pockels cell** An electro-optic switch that rotates the polarization of a light beam passing through a mate-

- rial when an electric field is applied to the material in the direction of beam travel (Pockels effect).
- **pointing** Positioning a beam to the correct angle as it passes through an optical component at full size (near field). Pointing can also be described as centering a beam focal spot on the pinhole in a spatial filter pinhole plane (far field). See centering.
- polarizer An optical element that separates the two polarization states of a light beam. The polarizers used on NIF are thin-film polarizers consisting of a specially designed multilayer coating applied to an optical glass substrate.
- preamplifier beam transport system (PABTS) An optical system that transports the beam from the preamplifier module to the injection system in the transport spatial filter.
- **preamplifier module (PAM)** A NIF component that is a self-contained package (LRU) that amplifies a shaped input pulse from an optical fiber to a level of about 10 J. The output from the PAM is split four ways into the four beams of a 2×2 quad.
- pupil relay system See relay imaging.
- **pyrolitic graphite** A highly pure form of graphite manufactured by chemical vapor deposition.
- quad A "quad" is a 2 × 2 array of NIF beams. It is the basic building block of both the PAM and the beam transport system from the laser to the target chamber. Each bundle contains two quads, one routed to the top of the target chamber and the other to the bottom.
- Raman scattering Stimulated Raman scattering (SRS) is an interaction between light waves and molecular vibrations or rotations in a material that leads to the growth of the molecular vibration or rotation and a second, scattered light wave. It is an undesirable effect in large lasers.
- regen See regenerative amplifier.
- **regenerative amplifier** A multipass amplifier having a large number of passes. As used in NIF, an amplifier stage in the preamplifier module.
- relay imaging, relay plane See image relay.
- relay telescope See spatial filter and image relay.
- **reservation** A framework that assures orderly access to shared equipment.
- **reticle** A pattern inserted into an optical path to aid in measuring angles or positions.
- **rod amplifier** An amplifier whose active element is in the shape of a glass rod (cylinder). See amplifier slab.
- Roots blower A type of high-volume vacuum pump. schlieren technique A technique for emphasizing light scattered from small structures on an optical component. The main beam is blocked at a focal plane, and the only light remaining is the high-spatial-frequency noise on the beam that lies outside the main focal spot. This is the inverse of the usual pinhole spatial filtering.

- sequence control language (SCL) A framework that implements a sequencing language used to execute user-defined and SCL-defined commands within a subsystem. Each subsystem determines which of its commands may be executed by SCL sequences.
- **serrated aperture** A type of apodizer. See apodizer. **server** An object is a server in an interaction with another object (the client) if it is the passive object which is invoked by a subprogram call.
- smoothing by spectral dispersion (SSD) A technique for beam smoothing in which a diffraction grating disperses a broad-band beam through a slight angle. This causes motion of the small-scale speckle structure in the spot on the target and tends to average over intensity nonuniformities in the spot.
- **software tool** A computer program used to help develop, test, analyze, or maintain another computer program or its documentation; for example, automated design tool, compiler, test tools, maintenance tool.
- solgel As used here, a technique for applying antireflection coatings to optical elements. The coating is composed of ~50-nm particles of silica (SiO₂) deposited from an alcohol solution.
- **spatial filter** An arrangement of two lenses, separated by the sum of their focal lengths, with an aperture at the common focus to restrict the range of angles in a beam of light.
- **speckle** Random irradiance fluctuations in a beam caused by interference of randomly phased small
- **status monitor** A framework that defines strategy to acquire status information from various NIF components.
- streak camera An instrument for measuring very fast events. A slit allows a one-dimensional strip of a light beam to strike a photosensitive cathode. Electrons emitted by the cathode are manipulated to form a two-dimensional image in which one dimension is the strip and the other dimension is time.
- **taxon** the name applied to a taxonomic group in a formal system of nomenclature. In NIF, the taxonomic name of a NIF device classifies it according to its location within the hierarchy of the laser assembly.
- Title I, II, III Project stages as defined by the Department of Energy in DOE Order 4700.1 or the DOE Glossary. In brief, the completion of Title I means that the project design is completed to a level of detail that allows a reliable cost estimate, and the completion of Title II means that drawings and procurement packages are completed to a stage that they can be sent for procurement of the buildings and components. Title III activities

- are project activities that follow procurement and occur before the facility is turned over to operations personnel. These include acceptance tests, installation, and any engineering modifications that are required.
- **transporter** A forklift-type device for moving LRUs to different locations.
- **transport spatial filter (TSF)** In NIF, the 60-m-long spatial filter that lies between the laser and the target area.
- **trigger pulse** A signal that commands an instrument to start.
- **tripler** A frequency conversion crystal that sums 1ω and 2ω beams to give 3ω .
- **trombone** An optical path of adjustable length used to equalize the propagation distance of two or more beams.
- **turbomolecular drag pump** A type of high-vacuum pump.

- vacuum manifold See plenum.
- **VME bus** Versa Module Eurocard bus—an industry standard bus for embedded systems.
- wavefront error The phase error on an optical beam caused by the accumulation of small errors in optical components (fabrication uncertainty, inhomogeneous material, mounting distortions, etc.)
- 1ω The fundamental frequency of a neodymium glass laser, corresponding to an infrared wavelength of 1053 nm (commonly called "red").
- **2**ω The second harmonic of a neodymium glass laser, corresponding to a visible wavelength of 527 nm ("green").
- 3ω The third harmonic of a neodymium glass laser, corresponding to an ultraviolet wavelength of 351 nm (commonly called "blue").

NIF ACRONYMS

ACS	access control system	GXI	gated x-ray imager
AGV	automated self-guided vehicle	HEPA	high-efficiency particulate air
AMPLAB	Amplifier Module Prototype Laboratory	HVAC	heating, ventilation, and air conditioning
ATM	asynchronous transfer mode network	IBE	interstage beam enclosure
$BK7^{TM}$	a standard borosilicate optical glass	ICCS	integrated computer control system
	(Borosilikat Kron 7)	ICF	inertial confinement fusion
BLDS	bottom loading delivery system	ICS	industrial controls system
CEA	Commissariat a l'Energie Atomique	IDL	interface definition language
	(French Atomic Energy Commission)	IOM	integrated optics module
CCD	charge-coupled device	ISS	integrated safety system
CCI	Cleveland Crystals, Inc.	ITS	integrated timing system
CCRS	chamber-center reference system	KDP	KH ₂ PO ₄ crystal
CD	conceptual design		(potassium dihydrogen phosphate)
CDR	conceptual design report or review	KD*P	KD ₂ PO ₄ crystal
CORBA	common object request broker architecture		(potassium dideuterium phosphate)
CPU	central processing unit	KPP	kinoform phase plate
CSF	cavity spatial filter	LANL	Los Alamos National Laboratory
CSG	color separation grating	LEH	laser entrance hole
CS&T	core science and technology	LLE	Laboratory for Laser Energetics, University
	(LLNL laser research not part of the NIF		of Rochester, NY
	project)	LLNL	Lawrence Livermore National Laboratory
CVD	chemical vapor deposition	LM	laser mirror
CW or cw	continuous wave	LMJ	Laser Megajoule
DAS	data acquisition system		(laser project in France comparable to the
DIM	diagnostic instrument manipulator		NIF)
DOF	degrees of freedom	LM1	laser mirror 1 (a deformable mirror)
EMI	electromagnetic interference	LRU	line-replaceable unit
EMP	electromagnetic pulse	LTAB	Laser and Target Area Building
FAU	frame assembly unit	MA	Main amplifier
FEM	facility environmental monitor	MOR	master oscillator room
FEP	front-end processor	MTV	maintenance transport vehicle
FF	far field	NF	near field
FOA	final optics assembly	NIF	National Ignition Facility
FOC	final optics cell	NS	neutron spectrometer
FOV	field of view	OAB	Optics Assembly Building
FXI	framing x-ray imager	OPG	optical pulse generator
GFRC	graphite fiber-reinforced carbon	P-V	peak-to-valley
GUI	graphical user interface	PA	power amplifier

PABTS	preamplifier beam transport system	SQL	structured query language
PAM	preamplifier module	SRS	stimulated Raman scattering
PAMMA	preamplifier module maintenance area	SSD	smoothing by spectral dispersion
PASS	preamplifier module support structure	SXI	static x-ray imager
PEPC	plasma-electrode Pockels cell	SY/TA	switchyard and target area
PLC	programmable logic controller	T&H	transport and handling
RP0	relay plane zero	TCP/IP	standard internet communication protocol
SBS	stimulated Brillouin scattering	TL	top loading
SCL	sequence control language	TRXI	time-resolved x-ray imaging system
SF	spatial filter	TSF	transport spatial filter
SIS	safety interlock system	TWTT	two-way time-transfer technique
SL	side loading	VME	Versa Module Eurocard (bus)
SNL	Sandia National Laboratories	XSSC	x-ray streaked slit camera

INERTIAL CONFINEMENT Lawrence Livermore National Laboratory

Monthly Highlights

September 1997

UCRL-TB-128550-97-12

Nova as a "20-Beam" Laser. We have effectively doubled the number of beamspots on Nova by propagating two different pulse shapes on each half of the 10 Nova beamline split-glass amplifiers. Using a single lens, the pulses from each half are partially defocused at the target plane to provide two adjacent beam spots with a continuously adjustable power ratio. Applied to a cylindrical hohlraum target, this "20-beam" Nova variant provides a NIF-like two-ring irradiation geometry for testing advanced symmetry control concepts required for achieving ignition.

NIF AMPLAB. We have performed gain measurements on a full-size 4-slab-high \times 2-slab-wide \times 1-slab-long prototype amplifier with a flashlamp pump cavity nearly identical to the NIF baseline amplifier design. The results, which were in excellent agreement with 2D ray-trace code predictions, are consistent with the NIF amplifiers achieving an aperture-average gain coefficient of 5% /cm. The prototype amplifier, shown below, had a full complement of laser glass and was outfitted with specially shaped flashlamp reflectors and antireflective coatings on the blastshields to increase pumping efficiency.



The assembled amplifier seen from the north mirror tower.

NIF Construction. NIF construction packages for the site preparation, foundations, the laser building shell, and the optics assembly building were awarded on schedule. The first contract (under \$1M) was awarded to Red Top Construction of Hayward, California. Digging the "big hole" was done by Teichert Construction of Stockton, California, in a contract under \$2M. The third contract, of \$4.2M (to do the foundation and concrete slab work) was awarded to Walsh Pacific of Monterey, California. The \$11.4M contract for constructing the laser building shell was awarded to Neilson Dillingham of Pleasanton, California. Preparations for the remaining construction contracts are proceeding on schedule.

NIF KDP Rapid-Growth Program. Over the last few months, a great deal of progress has been made in the rapid growth of KDP and KD*P (deuterated) crystals for the NIF. Shown below is a KDP boule measuring $57 \times 57 \times 47$ cm, which is the minimum size required for NIF second-harmonic-generation crystals. Larger, crack-free, and higher-optical-quality crystals resulted from thermal expansion coefficient matching of the growth-platform base plate to the crystal material. An additional KDP boule measuring $55 \times 55 \times 38$ cm was grown with a continuous filtration system installed and operating for the duration of the run. Crystals grown in small tanks with continuous filtration have been tested and show a significant improvement in damage threshold over those grown without constant filtration.

A KD*P boule measuring $52 \times 51 \times 38$ cm has also been grown, but it does not have sufficient height to yield a third-harmonic-generation plate. Experiments are under way to increase the aspect ratio of these crystals. We have demonstrated NIF damage thresholds in small KD*P boules, but have not yet evaluated the 52-cm boule. The large crystals still contain some inclusions, so work continues on improved system design and process optimization.



 $57\times57\times47\text{-cm}$ KDP crystal.

NOVA/BEAMLET/NIF UPDATES APRIL-JUNE 1997

G. Hermes/R. Speck/A. Clobes

Nova Operations

During this quarter, Nova Operations fired a total of 176 system shots resulting in 205 experiments. These experiments were distributed among ICF experiments, Defense Sciences experiments, X-Ray Laser experiments, Laser Sciences, and facility maintenance shots.

Smoothing by spectral dispersion (SSD) on all 10 beamlines of Nova was activated during this quarter. In addition to the activation of the SSD system in the preamp section of the laser, this change also included the installation of double debris-shield holders on all focus lens assemblies of the 10-beam chamber. The double debris-shield holders contain both the kinoform phase plates (KPPs) and a debris shield to protect them from target debris resulting from a shot. Activation required several days of beam propagation evaluation and system performance verification. The application of SSD and KPPs produces an improvement in spatial smoothness of the focal spot on target.

We have started the installation of the 4ω probe beam for the 10-beam target chamber. This beamline will be created by a "pick-off" mirror installed into the center obstruction of beamline 8 in the switchyard. This subaperture, 1ω beam will be propagated to the 10-beam chamber where it will be converted to 4ω and used as a target diagnostic probe beam. Installation will continue through this quarter, with system activation scheduled for next quarter.

The Los Alamos Full Aperture Back Scatter Imager was installed on beamline 7 in the target area. The primary purpose of this instrument is to provide timeresolved target-plane images of the stimulated Raman (SRS) and stimulated Brillouin (SBS) backscatter emission. In addition, the instrument will measure the energy and time-integrated near-field pattern of the SRS and SBS backscattered light.

In continuing support of the Petawatt project, the Petawatt minichamber was received and is being

cleaned and prepared for installation in January of 1997. This minichamber will be used during the initial Petawatt demonstration to measure system performance and beam focusability. The 32-in. gate valve between the compressor chamber and the minichamber was installed. The fabrication of the parabolic mirror system vacuum housing, extension tube, and gimbal rings by Bechtel Nevada was completed and received. The parabolic mirror is due in early February of 1997. The details of the Target Alignment Viewer and Target Inserter have been completed, and fabrication of these systems has started. The backscatter diagnostic table and enclosure were also installed. These systems will be installed and activated on the minichamber late next quarter.

Tests comparing the performance of a Princeton Instruments charge-coupled device (CCD) camera to film was completed. The results show that the CCDs compare favorably with film. The details of this evaluation are being compiled, and a report will soon be available. Further comparisons of CCDs and film coupled to a microchannel plate on an x-ray source are continuing.

We have started planning for the decommissioning of the Nova Two-Beam Target Area. The hardware in this area will be disassembled and removed for salvage or storage as appropriate. Experiments in the Two-Beam area will end in September of 1997. The area must be clear for activation of the National Ignition Facility (NIF) optics processing facility by mid-December of 1997.

Beamlet

Beamlet continues to provide the test bed to validate the laser physics foundations of the National Ignition Facility (NIF) and to check laser engineering concepts and components proposed for the NIF. During the first quarter of FY 1997, activities on

Beamlet included the following:

- 1. Reactivation of the laser following the lens implosion caused by side-scattered stimulated Brillouin scattering (SBS) during the long-pulse campaign in September of 1996.
- 2. Installation and activation of beam smoothing by one-dimensional smoothing by spectral dispersion (1-D SSD) on the Beamlet preamplifier.
- 3. Initial detailed beam-quality characterization of the injected near field.
- 4. Installation and alignment of NIF prototype square spatial filter lenses.
- Recalibration of existing wavefront sensors and installation of additional higher-resolution sensors in preparation for detailed wavefront characterization shots, planned for January 1997.

The prevention of vacuum barrier optics damage and implosion is critical for the NIF design. Analysis of failed lenses has shown that a significant reduction of the internal stress can prevent formation of multiple cracks, in addition to increasing the critical flaw size. Modifications were completed to install tilted square lenses in all Beamlet spatial filters. These have a stress significantly lower than the original round lenses, and are comparable to Nova spatial filter lenses (<900 psi). The tilted lens design required a complex alignment procedure to maintain the overall static aberration below two waves peak-to-valley.

An operational readiness review and fault analysis were completed before reactivating the laser. Several measures were implemented to reduce the SBS sidescatter risk, including real-time bandwidth sensors for the master oscillator room and regenerative amplifier. An optical fail-safe system is being designed and tested, and will be installed in the Beamlet Master Oscillator later in FY 1997, complementing the existing electronic fail-safe system.

While system reactivation activities took place on the main laser, several campaigns were completed to characterize the Beamlet injection beam. This information is required to complete the Beamlet propagation model and noise analysis by the NIF Project. Near-field measurements were performed using an additional diagnostic system and confirmed a contrast level of 5%, consistent with model predictions of Beamlet output noise level and preamplifier modeling.

Beam smoothing is an important requirement to optimize target irradiation on the NIF, and Beamlet will test the proposed scheme using 3- to 5-Å bandwidth, critically dispersed in one axis using a grating in the preamplifier (1-D SSD). A first step towards this test was the installation of the preamplifier dispersive optical system and a verification of its operation at the injection plane. Near-field, far-field, and time-resolved power measurements confirmed predicted behavior. Speckle smoothing was tested with a small phase plate in the test setup.

National Ignition Facility

The principal activity for the NIF Project during this quarter was the completion of the Title I Review process, which included the Independent Cost Estimate (ICE). The Title I Design Review (i.e., for Preliminary Design) was completed November 22, 1996. No issues were identified by the review committee that would preclude starting Title II Design (i.e., Final Design) and long-lead procurements. The ICE Review draft report was completed as scheduled on December 6, with overall estimates in excellent agreement (within about 1%) with the project estimate. The Project requested and DOE/OAK granted approval to initiate Title II design and long-lead procurements. Title II design and long-lead procurements are underway, and progress has been made in all areas.

Title I Design Review

The Title I Design Reviews were completed in accordance with the *NIF Title I Review Plan*. Formal presentations were made by the Project to the Review Committee consisting of external and internal reviewers with significant expertise in their areas of review.

The review was divided into these main areas:

- Conventional Facilities.
- Optical Design and Laser Performance.
- Laser System.
- Beam Transport System.
- System Control.
- Target Experimental System.
- Optical Components.
- Operations Engineering.
- Integrated Computer Control System.
- The Conventional Facilities Design Review covered the site improvements, Laser and Target Area Building (LTAB), and OAB. Based upon the presentations and the review of numerous design documents provided, the committee submitted extensive comments. While there were numerous important findings, the Committee determined that the NIF Conventional Facilities Title I Design meets the system requirements and is the minimum platform to meet the NIF functional requirements. The Committee recommended proceeding to Title II design.
- The Laser System reviews included the amplifier, Plasma Electrode Pockels Cell (PEPC), power conditioning, and auxiliary subsystems. Three areas of concern (optical pulse generation, pulse-power switch, and amplifier blast shield/seal) were identified by the Review Committee as requiring management attention early in Title II Design.

The majority of the Title I Design reviews turned up no significant items to resolve before Title II. Following the review, the summary recommendation of the Review Team was "to accept the designs with comment, and proceed with Title II Design." Title II Design started following DOE/OAK approval. There are, however, three areas of concern (optical pulse generation, pulse power switch, and amplifier) that will be addressed in initial Title II Design. As each area of the Project completed its Title I Review, the engineering effort in that area switched to Title II Design.

Based on the Title I Design Review, the *Primary Criteria and Functional Requirements* (PC/FR) for Title II and the *Project Data Sheet* were updated and approved by the Level 1 Baseline Change Control Board (BCCB1) in Washington, D.C. An update of the Title II design criteria based on Title I Design Review results was completed and incorporated in two proposed Baseline Change considerations: (1) Title I update of *Primary Criteria and Functional Requirements* (BCP97-001) and (2) *Project Data Sheet* update (BCP97-002). These proposals were approved by the BCCB1 on December 20, 1996. The *Project Data Sheet* update was submitted to the Secretary of Energy for consideration.

The Title I planning included an accelerated transition to operations in support of the user community. The Title I schedule and planning define the basic strategy for the NIF Project and the ICF Program to implement a smooth transition between construction and operations to support Defense Programs' Stockpile Stewardship and Management Program (SSMP).

Other Activities

In the Beam Transport System, the design was modified to reflect an optimized 48-PAM structure (not to preclude 96 units). In collaboration with Conventional Facilities, the height of the switchyard concrete building was decreased by 2.5 ft from the Title I design as a cost saving measure. The switchyard space-frame column and mirror-support locations were revised, and dynamic analysis verified that the stability meets specification. Analyses have been completed to support a change to increase the spatial filter lens thickness, thereby reducing the lens stress to 500 psi (from 700 psi) in order to provide an increased safety margin.

In reworking the Preamplifier System for the new 48-PAM design, the functions and design specifications for the splitter section of the Preamplifier Beam Transport System (PABTS) were refined. (The reduction in number of PAMs necessitates a beam-splitter section to inject light from 48 PAMs into 192 beams.) Specifically, the requirements for optical-path-length adjustability and energy-splitting adjustability were developed further based on comments from the Title I review. In addition, the merits of splitting a single PAM's output into a single quad were evaluated.

Significant advances were made in preparation for the Conventional Facilities construction:

• The Project Labor Agreement with national, state, and local labor unions that reduces sched-

- ule risks and cost impacts due to potential labor disputes during Conventional Facilities construction was finalized by the Parsons negotiators. The agreement has been signed by the Union Representatives and is awaiting Project Office approval.
- The Owner-Controlled Insurance Program has been approved. This initiative reduces conventional facility construction bid costs and improves site construction safety.
- An updated, integrated schedule for Conventional Facilities construction packages was prepared and distributed. The Conventional Facilities construction management plan was developed.
- The Title II design for the first construction package, Site Preparation, is nearing completion and is on schedule for completion to meet the project milestones leading to the beginning of Site Preparation on March 11, 1997.

During this quarter significant progress has also been made in various areas of the Core Science and Technology (CS&T) Program, which supports the NIF Project:

- Selected design details of the 40-cm deformable mirror are being reevaluated following experience gained from assembly and testing of a full-scale prototype mirror built in the CS&T Program. In particular, it may be possible to simplify the method of attachment of the actuator assemblies on the back side of the substrate.
- The 4 × 2 NIF prototype amplifier activation in AMPLAB has made good progress.
- Assembly of a NIF prototype 2 × 1 PEPC was completed in collaboration with CS&T, and testing started. This unit validates most of the important design features in the NIF design, including a two-aperture-long plasma charging two crystals in parallel; validation of anodized Al as a PEPC housing; and integration of vacuum and electrical interfaces at the end of the 2 × 1 PEPC, thereby allowing closepacking of PEPC Line Replaceable Units (LRUs) in the NIF.

Advances in power conditioning development included the following:

- In collaboration with CS&T, half-current (250kA) testing of the ST-300 spark gap switch was completed, and full-current testing began. Flashlamp triggering tests at American Control Engineering validated the flashlamp triggering strategy for the NIF pulse-power system.
- A NIF prototype power conditioning module operated (SNL-Albuquerque) for over 400 shots at full specified voltage and current (25 kV, 500 kA).

- A spark-gap switch was operated (SNL-Albuquerque) for 100 shots. The measured resistance was higher than expected. Reduced delivered energy (~5%) will be addressed if the measurements are validated.
- Power conditioning system testing is continuing at American Controls Engineering. Reliable triggering of flashlamps was demonstrated at a favorable 12 kV, which is one-half the specified voltage. Permitting and assurance activities included the following:
- The Record of Decision (ROD) for the Programmatic Environmental Impact Statement on Stockpile Stewardship and Management was published by DOE on December 11, 1996, establishing LLNL as the NIF site. The ROD was a critical-path constraint on start of construction, procurement, environmental permits, and Critical Decision 3.
- Environmental permit applications were completed and submitted to the regulatory agencies following release of the ROD. These permits are required prior to the beginning of site preparation.
- A significant effort was directed to complete the draft of the *Construction Safety Program* document, which is the overall safety document for construction and special equipment subcontractors and Laboratory personnel at the LLNL site. The activity involves Conventional Facilities, Hazards Control, and Project Assurances.

- The second Public ES&H Working Group meeting was held on October 7, 1996. The briefing included seismic design, decontamination and decommissioning for Nova and NIF, and bounding accidents.
 - Optics activities included the following:
- The first full-scale NIF crystals were obtained from a rapid-growth KDP crystal. The two 41-cm Z plates met the NIF transmitted-wavefront specification. Witness samples from the crystal met the 1ω damage requirement. A photothermal deflection technique as a diagnostic for precursor to KDP bulk damage was demonstrated.
- Two out of four full-sized mirror substrates were manufactured to NIF specifications using the NIF manufacturing process. Coated mirrors will be demonstrated on Beamlet in 3Q FY97. Also, spatial filter lenses that meet NIF powerspectral-density and roughness specifications were manufactured using NIF processes.
- The large-aperture optics drawing package (80 drawings in total) was delivered to the NIF Optics Production group for use in their preparation for long-lead optics procurements. These drawings, which were developed to a near-Title II level of completeness and detail, contain near-final specification information for procurement of the over 7,000 large optical components in the NIF.

Nova/Beamlet/NIF Updates January–March 1997

R. Ehrlich/P. Wegner/S. Kumpan

Nova

Nova Operations performed 201 full system shots, resulting in 213 experiments during this quarter. These experiments supported efforts in ICF, defense sciences, university collaborations, laser sciences, and Nova facility maintenance. The Nova shot rate continues to be impacted by facility funding reductions. The process of moving Nova Operations personnel into National Ignition Facility (NIF) related positions will continue, eventually resulting in Nova operating 1.5 shifts per day. Also impacting the shot rate for the quarter was a three-week period during which the first shift of each day was dedicated to facility maintenance. The Nova Operations personnel efficiently used the added maintenance time to perform deferred maintenance tasks and to expedite progress on system upgrades and additions.

The first series of implosion experiments was performed with kinoform phase plates (KPPs) on all ten beamlines. We were successful in maintaining the accuracy of precision pointing and power balance with the KPPs at levels sufficient to produce symmetric implosions. The first target-shot series with smoothing by spectral dispersion and KPPs on all ten beamlines was also successful. We achieved the desired bandwidth (2.4 Å at 1ω) with acceptable levels of temporal and spatial modulation on all beamlines.

The Petawatt Project efforts concentrated on preparing for the first series of shots into the new Petawatt target chamber in late April. The target chamber was cleaned, assembled, and installed early in the quarter. By the end of the quarter, the target chamber had been integrated into the Nova vacuum system with new hardware and software, then pumped down to a satisfactory vacuum level. The parabolic mirror, beam

alignment, target insertion, target alignment, and target diagnostic systems were installed. Tests of these systems will be performed in early April.

The 4ω probe beam was successfully installed on the ten-beam target chamber. Off-line testing of the frequency conversion system has been completed. Online testing and tuning will commence early next quarter. Plans are being formulated to use this beamline, which uses light taken from the center obscuration of beamline 8, as a probe beam for experiments in the Petawatt target chamber.

The preparations for decommissioning the Nova twobeam target area continue. The system will continue to operate until mid-November to allow for the completion of 100-TW and equation-of-state experiments. The area will be clear by mid-January, when we will begin work to convert it into a NIF optics processing area.

Beamlet

Beamlet continues to provide a testbed for validating the laser physics foundations of the National Ignition Facility (NIF) and for evaluating laser engineering concepts and components proposed for the NIF. During the second quarter of FY 1997 activities on Beamlet included the following:

- Characterization of beam quality at the output of the Beamlet front end to validate noise propagation models and to support the development of optical specifications for the NIF preamplifier module.
- Optimization of the laser wavefront using the Beamlet adaptive optics system to gauge compliance with NIF focusability requirements and to provide a baseline for testing a prototype NIF deformable mirror.

- 3. Successful testing of a 40-cm NIF prototype deformable mirror inside the main amplifier cavity.
- Propagation of full system shots with angularly dispersed bandwidth to test the 1.06-μm laser requirements for producing 1D beam smoothing at NIF targets.

Modifications to the facility included a safety upgrade to dual-camera inspection systems for all four spatial filter lenses, as well as the removal of the frequency converter enclosure at the output of Beamlet to make way for installation of the final optics test mule.

The measurements performed on the Beamlet front end confirmed that the beam injected into the main amplifier is of high quality. In the absence of active wavefront correction, the injected beam is near-diffraction limited, with 80% of the power contained inside a divergence half angle of 4.3 μ rad (for a 34-cm beam). The distortion of the measured wavefront is 0.1 wave rms, and the calculated Strehl ratio is 0.7. Amplitude modulation in the near field was measured to have an irradiance contrast of 5%, confirming model predictions that the small amount of modulation observed in the output beam at low power is driven by contributions from the front end.

Beam divergence at the output of the laser was characterized with the Beamlet adaptive optics system (AOS) optimized to correct for wavefront distortions incurred in the main amplifier. Emphasis of the tests was on establishing best attainable divergence at low power in the angular regime below 20 to 30 μrad to help ascertain wavefront gradient requirements for NIF optical components. Performance was monitored with radial shearing interferometers that measured near-field wavefront at the input and output of the main amplifier with a spatial resolution of 1 cm, and with cameras that measured the corresponding intensity distributions in the far field with an angular resolution of 0.3 μ rad. Test results show that pumping the Beamlet amplifiers induces 1.8 waves of long scalelength distortion over the 34-cm beam that is fully correctable with the Beamlet AOS. Passive distortions in the system total ~2 waves peak to valley and are only partially correctable, resulting in a residual error of 1 wave peak to valley, 0.2 wave rms. The resulting output beam has 80% of the power contained inside a divergence half angle of 10 to 11 μrad, and a Strehl ratio of 0.5.

A prototype 40-cm deformable mirror and controller were provided by the NIF Wavefront Controls and U-AVLIS Adaptive Optics groups. The mirror was installed and tested in the multipass cavity at an end mirror position adjacent to the amplifier modules. No evidence of coating damage or degradation to the actuator assemblies was observed for the 11 shots in which the mirror was exposed to flashlamp radiation. Output wavefront was not as good as that obtained

with the Beamlet deformable mirror because of a figure error of 1 wave peak to valley in the large mirror that was incurred during fabrication. The advantages of distributing large wavefront correction over two passes of the cavity were addressed by examining the pass 2 focal spot in the cavity spatial filter. With 3 waves of correction, an approximate 25% reduction in spot size was observed over the case where the correction is applied in the front end, although the irradiance level at the edges of the pinhole was not measured.

1D beam smoothing by spectral dispersion (SSD) was successfully tested for the 1.06- μ m part of the laser at output powers up to 3.5 TW in 1-ns pulses. Bandwidth of 2 Å was generated with a 6.7-GHz phase modulator and angularly dispersed in the Beamlet front end to produce an output divergence of 25 μ rad, consistent with NIF indirect-drive requirements. Testing was performed with the pinhole in the transport spatial filter removed to better observe nonlinear growth of beam modulation in the laser. For B integrals in the booster amplifier stage of 1.4 rad corresponding to the maximum power tested, measurements showed a high-quality output beam with no increase in near-field modulation over the non-SSD case.

National Ignition Facility

The primary focus of the NIF Laboratory Project Office for the second quarter of FY 1997 was to complete the revision of the project baseline in accordance with the directives of the DOE Headquarters (HQ) Level 1 Baseline Change Control Board (BCCB1). This activity, namely in the form of the FY 1998 Project Data Sheet, was approved and forwarded to the Secretary of Energy in December 1996; it culminated in a proposed new baseline to be documented in an updated *Project Execution Plan*.

Critical Decision 3, Approval to Begin Construction, was signed by the Acting Secretary of Energy on March 7, 1997. This top-level milestone for the NIF Project was achieved ahead of schedule, allowing the Project to proceed with construction activities at the selected site, Lawrence Livermore National Laboratory (LLNL).

The Notice to Proceed for the first Construction Subcontract Package, Site Preparation, was given on March 18, 1997. After the notification was issued, site work began on March 31, 1997, with preparation of the construction laydown area (Kirschbaum Field) for the installation of the construction management trailers.

Key activities supporting construction and completed as scheduled include the following:

- Execution of the NIF Project Labor Agreement, a key to the construction strategy.
- Implementation of a Project-specific Construction Safety Program, which was included in the first construction package.

- Completion of a traffic survey.
- Approval of an Owner Controlled Insurance Program.
- Award of a broker contract.

The final *Independent Cost Estimate Report* was completed and released, and all action items were completed.

Revision 1.6 of the *Primary Criteria and Functional Requirements* was completed in accordance with the Level 1 Baseline Change Control Action, and a description of the process for developing the ES&H criteria using DOE's *Work Smart Standards* was prepared.

At the request of the BCCB1, the NIF Laboratory Project Office prepared and submitted to DOE's Oakland office (DOE/OAK) the NIF Project Completion Criteria. This document specifies the criteria for completion of the NIF Project and for achieving Critical Decision 4 in September 2003, consistent with the Project baseline revision effort. The overall strategy for completion enables the ICF Program to begin experimental operations in support of Stockpile Stewardship and other programmatic missions at the earliest possible date, as NIF performance capability is building up toward the eventual goals set out in the Primary Criteria and Functional Requirements.

The NIF *Mitigation Action Plan* (MAP) has been formally transmitted by DOE/OAK. The MAP's purpose is to describe how to mitigate environmental impacts identified in the *Record of Decision* and the *Final Programmatic Environmental Impact Statement for Stockpile Stewardship and Management*. The first MAP action was placing public notices of the start of construction in all local papers and the *San Francisco Chronicle*.

Working with the NIF System Integration team and DOE/OAK and using the DOE guidelines for Necessary and Sufficient (Work Smart) Standards, the NIF Project Assurances team developed the final draft of a document describing the process for preparing the *Primary Criteria and Functional Requirements*. This and revision 1.6 of the *Primary Criteria and Functional Requirements* were signed at DOE/HQ.

Site and Conventional Facilities

The Project began the transition to the construction phase for the NIF Conventional Facilities. The first construction subcontract package was awarded as scheduled, and construction began on Construction Subcontract Package 1: "Duct Bank Relocation and Parking Lot Relocation." The construction laydown area where the construction management complex is located (Kirschbaum Field) was prepared for construction management trailers.

In addition, the Title II design for Conventional Facilities saw the completion of several design review packages:

 The "Target Building Mat and Laser Bay Foundation" (Construction Subcontract Package 3) was received for Title II 100% review.

- The "Target Area Building Shell" (Construction Subcontract Package 6) 65% review comments were received.
- The "Laser Building Buildout, Site, and Central Plan" (Construction Subcontract Package 9) was received for Title II 65% review.

Special Equipment

- The optomechanical layout of the pre-amplifier module (PAM) has been updated to reflect the optical component design currently under analysis. The beam size in the multipass amplifier section has been increased from 23 mm to approximately 27 mm. As a result, several of the 50-mm optics will need to be increased to 75 mm
- The 50-mm Nova rod amplifier head has been installed and activated in the preamplifier integration testbed. Gain, gain uniformity, and birefringence measurements under full loading have been completed. The 4-pass amplifier cavity has been set up and extraction experiments begun. Results will be available for the Technical Management Plan review scheduled in April.
- The impact of the optomechanical layout for the 1:4 beamsplitting assembly following the PAM and the location of the separate PAM power conditioning unit (PCU) with respect to the pre-amplifier support structure (PASS) in the beam transport system were evaluated. The PAM PCU will now be located on the Laser and Target Area Building floor beneath the PASS.
- After careful comparison between air and nitrogen, the amplifier cooling gas working group recommended that the amplifier flashlamp cooling gas be changed from air to nitrogen.
- The Power Conditioning development team worked to validate the NIF system design and answer Title I issues. Effort was concentrated on switch testing. The first full-energy, 1000-shot run was completed on the prototype module at Sandia National Laboratories (SNL) using the Physics International switch in self-break mode. Results showed that the 6-mm spark-gap erosion observed in initial tests grew to 18 mm after 1000 shots. Although the gap erosion rate exceeded that predicted by the manufacturer, this experiment demonstrated the feasibility of using the spark-gap switch in the NIF application.
- The Beam Transport design team concluded that a graded approach on spatial-filter interior surface finish should be used. This means that polished plate will be used for end and center vacuum vessels (near optics) and that bead-

- blasted surfaces will be used in the vacuum beam tubes. This decision allows the placement of the long-lead mill order after the vessel configuration is frozen.
- The Integrated Computer Controls System (ICCS) team developed the *Hardware Control Emulation Plan* to help guide the planning for the first of the ICCS software prototypes. Prototype frameworks for the configuration, system manager, generic front-end processor, status monitor, message log, and sequence control will be demonstrated in May. Four design reviews on these framework components were held in March. The object-oriented models for the prototype are complete, and coding of the associated software packages has commenced.
- The ICCS team developed a first-draft software test package that contains the essential elements of a full-scale benchmark test. The plan is to subject the NIF components, software tools, and networks (in a repeatable fashion) to simulated performance stresses expected during operation. A 'client' within the test package can exercise CORBA services that are used in the ICCS framework. Scale testing of the software is accomplished by operating any number of objects in any number of servers on any number of computers. Timing, memory usage, and results of sample calculations are measured. Initial tests of functionality and speed of performance were
- After problems associated with the behavior of an updated version of a third-party-supplied module were corrected, the two-way time transfer system was shipped to Jet Propulsion Laboratories (JPL). Measurements made at the supplier indicate that the timing performance meets expectations. Following JPL evaluation, the unit will be further evaluated at LLNL, and efforts to enhance performance to meet integrated timing system precision requirements will begin. The master clock source, which will serve both as a two-way time transfer system timing input and a network time server, has been ordered.
- A decision has been made by the Diagnostics design team that a set of four output sensors will not share the input of quads (of four beams) from adjacent bundles. The decision not to share was made due to the concomitant complexity of the relay optics and the lack of space that would be available for installation and alignment. Other methods of data sharing between the quads of adjacent bundles are being considered.
- A proposal was made by the Diagnostics design team to use each output sensor diagnostic cam-

- era simultaneously for two beams. Options for beam sizes and beam combination techniques were evaluated. A preliminary analysis was made of the performance of the 1ω diagnostic near-field camera with the required larger aperture. Options for 1ω diagnostic tower and relay beam layouts were considered; a layout was chosen as a compromise between minimizing potential damage problems and equalizing relay lengths. This new configuration eliminates the crossover beams, simplifying the component mounting requirements under the TSF vessel and improving access.
- The prototype large-aperture deformable mirror (DM) was tested on Beamlet this quarter. The purpose of the Beamlet tests was fourfold: (1) Assure that the DM survives flashlamp exposure with no adverse prompt effect due to electromagnetic interference (EMI) or thermal expansion and with no structural or cleanliness degradation due to flashlamp ultraviolet exposure to the epoxy. (2) Acquire data from which a Beamlet propagation model can be validated for wavefront and focus spot performance. This validated model can later be extrapolated to the NIF configuration and beam size. (3) Investigate the focus spot performance in the early cavity pinholes. (4) Test the NIF wavefront controller prototype on Beamlet. The DM was inspected after 12 Beamlet shots and showed no apparent degradation or discoloration. Also, the DM showed no evidence of adverse prompt effects due to EMI or thermal expansion.
- The target chamber Request for Proposal was released on January 27, 1997, to five potential offerors. Updating of drawings is ongoing through the Title II engineering phase, with the goal of releasing the package to the successful bidder in June. Vendor bids are due April 23, 1997.
- Further redesign of the target chamber has been done to accommodate last-minute requests for more diagnostic ports and an access port for the first-wall-servicing robot.
- Continuing work was done on assessing the cost and performance of hot-pressed B₄C and Al-B₄C cermet (metalized ceramic) for the first wall. A small R&D contract was developed with a potential cermet manufacturer to develop a cermet that meets NIF cost and performance criteria. X-ray fluorescence analysis was done on new cermets and hot-pressed B₄C to quantify whether they would meet performance specifications.
- We completed a preliminary investigation into the effects of the proposed new color separation grating on beam dumps. The current locations for the beam dumps appear to be satisfactory, and a nominal size of 1 m × 1 m (possibly just

over 1 m in one direction and just under 1 m in the other) should handle the first five orders of 1ω and 2ω light.

Optics Technology

- Schott Glass Technologies completed the construction of a 13,000-ft² building to house the NIF-size prototype of the continuous melter and installed melting and annealing equipment. A melting campaign is scheduled to begin in late April, with results available in the summer. A full-size BK-7 analog, continuously melted and formed, met NIF specifications.
- Hoya Optics completed fine annealing of continuously melted laser glass formed at half-scale; all properties except homogeneity met NIF specifications. Hoya received a building permit from the city of Fremont for its NIF laser glass facility and is moving ahead with the design. Facility construction will begin this summer and will be completed in FY 1998.
- LLNL grew a 51-cm KDP boule using rapid growth technology, demonstrating the size needed for the NIF second-harmonic generation crystals (i.e., Pockels cell crystals demonstrated in FY 1996). Improved platform design to

- improve crystal quality and minimize stresses is continuing and will be demonstrated in July.
- The Optics Technology group demonstrated new coating source material at each of the coating vendors, which will improve the spectral performance of polarizers. The damage threshold has been qualified on subscale parts; fullscale parts will be tested beginning in late April.

Upcoming Major Activities

During the third quarter of FY 1997, the NIF Project will begin its transition from strictly design to the initiation of Conventional Facility site work, the start of Special Equipment procurement, and the start of vendor facilitization in Optics. Site Preparation work will begin in April and should be completed in July, and the Site Excavation contractor was mobilized in June. In Special Equipment, the selection of the contractor for the Target Chamber should be completed, and award is planned for early August. In Optics, the facilitization contract for the amplifier slab fabrication facilitization should be awarded. Plans are also taking shape for the NIF Groundbreaking Ceremony, which will be held in May to mark the beginning of construction on the NIF site.

NOVA/BEAMLET/NIF UPDATES APRIL-JUNE 1997

R. Ehrlich/S. Burkhart/S. Kumpan

Nova Operations

Nova Operations performed 258 full system shots, resulting in 289 experiments during this quarter. These experiments supported efforts in ICF, defense sciences, university collaborations, laser sciences, and Nova facility maintenance. The shot rate was significantly above average this quarter, primarily due to increased reliability as a result of added maintenance time in January. Nova Operations was able to maintain a high shot rate while lending personnel to Beamlet and National Ignition Facility (NIF) to assist in the completion of project milestones.

Installation of the hardware required for "beam phasing" on Nova was completed in preparation for the initial experiments in early July. Beam phasing will provide the capability to irradiate indirectly driven Nova targets with two rings of beam spots on each side for studies of time-dependent second-Legendre and time-integrated fourth-Legendre flux asymmetry control. The timing and pulse shape of the outer rings of beams illuminating the targets will be controlled independently from those of the inner rings. This is achieved by propagating the pulse from the backlighter pulse shaping system down one spatial half of each beamline, while propagating the main pulse shape down the other half. When slightly defocused on target, the beam halves make two separate rings of spots on each side of the target.

The Petawatt project successfully completed the first two series of shots onto targets in the new Petawatt target chamber during this quarter. These shots placed up to 520 J of light on target in 5–20-ps pulses with a focal spot diameter of approximately 14 μ m FWHM (for the Fast Ignitor project). Diagnostics on the Petawatt target chamber worked well. The sources of hot electrons and their heating effects were explored with x-ray spectroscopic and neutron production measurements. The

peak irradiance achieved during these shots was about $10^{19} \, \text{W/cm}^2$. Peak irradiances of up to an order of magnitude higher are expected in the next quarter with pulses as short as $500 \, \text{fs}$.

Two significant target diagnostic capabilities for experiments in the ten-beam chamber were added this quarter. The 4ω probe beam was successfully tested and implemented on target shots. Also, the capability to delay beamlines 7 and 8 for up to 100 ns for x-ray backlighting of targets was added and successfully used.

Beamlet Operations

Beamlet completed a total of 61 system shots during 33 shot-days this quarter, with experiments on 1D beam smoothing by spectral dispersion (1D-SSD), spatial filter pressure tests, and pinhole closure. These experiments are all directed towards resolving scientific and engineering issues for the NIF. In addition, a number of system upgrades were completed. The highlights of these experiments are as follows:

- Concluded the 1D-SSD campaign that began in the second quarter of FY 1997. We reached 70% of the NIF red-line B-Integral with 1D-SSD, observing no unexpected effects. The experiments were concluded at this level to limit the fluence within the laser cavity until improved spatial filter lenses could be installed.
- Performed measurements on the allowable spatial filter background pressure for NIF. The Beamlet beam was resized to the correct f/# to simulate both the NIF cavity and transport filters.
- Made detailed pinhole closure measurements for various types of pinholes, including the standard "washer" type, offset leaf, and cone pinholes. This was done using time-resolved diagnostics, including a streaked pinhole interferometer and a gated optical near-field imager.

- Activated the NIF prototype wavefront controller, using the same hardware and software used in the second quarter for the large deformable mirror tests.
- Mounted a major engineering effort to conclude the final optics "Test Mule" installation. Initial thermal tests were completed with the Test Mule at vacuum.

Early in the quarter, we completed 6 shots on 1D-SSD at high power, using 200-ps and 1-ns pulses. B-Integral effects during SSD operation were not observed to be a problem, although we only reached 70% of the NIF red-line fluence, which is below where we expect to see major problems. The testing was concluded to avoid damaging the temporary lenses on the system, which were installed until we could obtain the replacement high-damage lenses.

In April, we installed the upgraded NIF deformable mirror controller in place of the original one that was on Beamlet since initial activation. The new system has advantages in maintenance and reliability and gives the NIF design engineers experience with the controller on a NIF prototypical system (i.e., Beamlet).

We performed 25 shots investigating effects of spatial filter pressure on output beam quality. The purpose for this series was to set the requirements for background pressure in the NIF cavity and transport spatial filters. The experiments were performed by bleeding air into Beamlet's transport spatial filter to reach specified background pressures in the range from 10⁻⁵ Torr to 10⁻³ Torr. At each pressure we fired a series of square 1-ns shots at increasing energy and determined beam perturbation by inspecting the output near-field beam profile. Simulating the NIF cavity spatial filter was simple; it has nearly the same f/# as Beamlet. However, to perform experiments relevant to the NIF transport cavity, we inserted a special beam apodizer in the front-end to shrink the beam to an effective f/80 on Beamlet. Beam breakup threshold for the NIF cavity and transport were measured at 6 mTorr and 2 mTorr, respectively.

Following the background pressure tests, Beamlet performed an 18-shot series on pinhole closure and backscatter. The goals for this pinhole series were as follows:

- 1. Determine the pinhole loading.
- 2. Measure closure time and phase shift at closure for the offset leaf pinhole.
- 3. Perform initial experiments on cone type pinholes.
- 4. Compare planar, offset-leaf, and cone pinholes with regard to back reflections.

Offset-leaf pinholes are a longitudinal dispersed variant of a square pinhole, where the four sides are offset to prevent plasma interaction between each of the sides. They were tested in both the square and diamond orientations using Ta blades. The ± 150 - μ rad square oriented

pinhole remained open for a 0.3-TW, square, 20-ns pulse, but closed at ~18 ns into a 0.43-TW pulse. The ± 100 - μ rad, square-oriented offset-leaf closed at 10 ns during a 0.05-TW pulse, while the same pinhole, diamond oriented, remained open for 20 ns at 0.10 TW.

The most promising pinhole is the cone pinhole, which has a cone angle of about twice the converging beam. The ± 100 - μ rad cone pinhole stayed open for 20 ns at 0.14 TW, although it closed when the power was increased to 0.17 TW. The NIF foot pulse is between 0.14 and 0.17 TW. A dramatic advantage of the cone pinhole is its near-total lack of back reflection, as discussed further below.

The pinhole backscatter experiments were performed with the following goals:

- 1. Determine the source of back reflections.
- 2. Compare the different pinhole geometries for backscatter performance.

Previous data suggested that the source of back reflection was the pinhole edges, especially if the final pinhole edges could be imaged back through the cavity pinholes. For diagnostic purposes, the pinhole plane was imaged in the west cavity diagnostics, and we clearly observed pinhole edge back reflection. The cone pinholes suppressed this by more than a factor of 10. Back-reflected energy from the cone remained insignificant at 3.5 TW, the highest power tested, which is a great advantage to injection mirror longevity. However, we did observe a large back reflection from the on-axis region of the pinhole for minor postpulses, underscoring the importance of controlling postpulses on the NIF.

May through mid-June was an intense period of activity to complete the "Test Mule," in which we will test NIF prototype final optics to high fluence and determine cleanliness requirements. The Mule consists of a temperature- and cleanliness-controlled vacuum chamber with a large access door and internal optical table for supporting the integrated optics module and final optics cell. While the chamber was put in place in April, a significant amount of work was required to install thermal controls, vacuum systems, and clean rooms. This was completed in June, and the system was successfully pumped down with window installed. Initial tests were performed on thermal performance, including direct and infrared camera measurement of the vacuum window temperature. The final week of June was spent on focal plane diagnostic alignment. We plan to install the final optics in early July, closely followed by system shots.

National Ignition Facility

During the third quarter of FY 1997, the NIF Project began its transition from strictly design to the initiation of conventional facility site work, the start of special equipment procurement, and the start of vendor facilitization in optics. Site preparation work began in April and will be completed in July, and the site excavation contractor was mobilized in June. The selection of the contractor for the target chamber was nearly completed, and will be awarded in July. The contract for the amplifier slab fabrication facilitization was awarded to Zygo Corp. in May.

There were no Level 0,1,2,3 milestones due during the third quarter. There were twelve Department of Energy/Oakland Office (DOE/OAK) Performance Measurement Milestones due; ten were completed within the quarter; and the other two (target area building shell, 100% design submittal, and optical design mid-Title II 65% review) have been completed as of the writing of this report.

The NIF Project Execution Plan (PEP) was updated, and the draft, including the updated project data sheet, is now being reviewed by DOE. The PEP is now consistent with the Level 0 Baseline Change Control Board (Secretary of Energy) action of January 1997, and with the detailed Project rebaseline prepared during the second quarter of FY 1997.

The major event for the third quarter was the Ground Breaking Ceremony, led by the Secretary of Energy and attended by approximately 2000 interested individuals, including distinguished members of Congress, the Department of Energy, the Department of Defense, the scientific community, the University of California, LLNL management, the Mayor of Livermore, national ICF Program managers, NIF Project personnel and their family members, and members of nongovernmental organizations.

The key assurance activities for the third quarter—to resolve the *Fire Hazards Analysis* recommendations, conduct the *Preliminary Safety Analysis Report* audit, conduct contractor audits, and oversee construction safety—are on schedule. Work on permits and National Environmental Policy Act determinations for soil reuse, along with the monitoring of the *Mitigation Action Plan* commitments, continues. As a special assignment, NIF Assurances supported DOE/HQ on the litigation of the *Programmatic Environmental Impact Statement for Stockpile Stewardship and Management*.

Site and Conventional Facilities

Progress to date is satisfactory on Title II design and bid and construction activities for Construction Subcon-tract Packages (CSPs) 1 through 4. Title II Conventional Facility design is critical path, driven by conventional facility construction package bid and award schedules, and special equipment technical performance requirements as described in interface control documents.

Construction is proceeding on schedule and within budget. The site preparation contractor will complete in July, and the excavation contractor is mobilized onsite and working. Implementation of the Owner Controlled Insurance Program has proceeded successfully on schedule, in budget, and to the performance standards established for this service.

Laser and Target Area Building (LTAB) Design. The following activities were completed during the quarter:

- Delivered CSP-3 (Target Building Mat and Laser Bay Foundations) and CSP-4 (Laser Building Shell) bid documents to Procurement.
- Completed Title II 65% design review for CSP-6 (Target Area Building Shell) and Title II 65% design review for CSP-9 (Laser Building Buildout, Site and Central Plant).
- Received Title II 100% design documents for CSP-9.

Optics Assembly Building Design. The Project completed Title II 100% design review for CSP-5.1 (Optics Assembly Building).

Construction Packages. There are many construction packages in various stages of completion as of this quarter:

- Construction on CSP-1 (Site Preparation) is currently 90% complete and planned to complete on schedule in July.
- Parking lots associated with the work were turned over on schedule to allow completion of the fencing of the construction site as planned.
- The contract for CSP-2 (Site Excavation) was bid and awarded this quarter, and the Notice to Proceed given on May 28.
- The excavation contractor mobilized on-site on June 19, and that work is currently 5% complete.
- The Invitation for Bid packages for CSP-3 (Target Building Mat and Laser Bay Foundations) and CSP-4 (Laser Building Shell) were issued.
- Two addenda have been issued for CSP-3, and bids are due late in July.
- CSP-4 bids are due early in August.

Special Equipment

The third quarter included much activity in the special equipment area.

Optical Pulse Generation. Commercially produced fiber amplifiers were received and characterized during this quarter. After some modifications by LLNL scientists, the commercial units demonstrated the critical NIF performance characteristics. Major procurements were placed for the prototype preamplifier module, including laser diodes, power electronics, and most commercial off-the-shelf hardware. An updated multipass amplifier cavity design was operated successfully with single-pass gain in excess of 25, exceeding the NIF requirements.

Amplifier. Dramatic progress was made during this quarter on the amplifier prototype laboratory activation. Preliminary tests were completed to assess the cleanliness performance of the NIF bottom-loading concept for the first time, using full-scale hardware and flashlamp light exposure. The results are very promising and indicate that there are no fundamental flaws in the amplifier installation and maintenance strategy. In addition, the first gain measurements were completed on the prototype amplifier in an effort to activate the large-area diagnostic system.

Pockels Cell. The 2×1 plasma electrode Pockels cell prototype was activated during this quarter, and its performance exceeded NIF requirements. The use of external currents to improve the plasma uniformity was demonstrated, and found to be crucial to meeting the NIF switching efficiency requirements. This system of "plasma spreading" is now being incorporated into the NIF baseline design. Drawings were completed and hardware ordered for the 4×1 mechanical and physics prototypes. The mechanical prototype will be used for testing maintenance strategies, kinematic mounting and alignment techniques, as well as transport interfaces.

Power Conditioning. Initial tests were completed during this quarter to validate the 500-kA switch (ST-300 from Primex Physics International). Four switches were tested, each with slight modifications to the design, in order to identify performance sensitivity. The results were quite positive: the switch appears to survive 1000 to 2000 shots at full power before requiring refurbishment, and no prefires were experienced other than those induced to gather safety factor data. A second switch design, from a different manufacturer, was also tested for 2500 shots at NIF operating conditions. The switch performed flawlessly, and inspection indicates that its lifetime might exceed 10,000 shots. Other design progress included a preliminary design of a solid-state trigger generator for the switch, which was also prototyped and operated successfully. The strategy for grounding the amplifier support structure to provide good bonding during a failure of the amplifier frame assembly unit insulation was investigated. Initial designs of this bonding system required increasing the mesh frequency in the LTAB slab to reduce the inductance of the system. Recent analysis indicates that enclosing the cables in the cable tray would have better performance than an improved slab ground grid. Therefore, a change to the LTAB design to increase the grounding mesh density in the slab is not likely to be required.

Beam Transport Systems. Mid-Title II (65%) design was formally reviewed by an independent team of engineers from within and outside the NIF project. All four subsystems were presented in separate sessions, and action items were recorded. No issues were identified that would result in a delay of Title II design

activities. A postreview effort was initiated to aggressively pursue all remaining interfaces to facilitate the completion of Title II. The long-lead procurement of stainless steel for spatial filter vacuum vessels was initiated with the on-schedule release of the first Request for Proposal. A recent engineering change to improve target irradiation symmetry during shots with subsets of beams has been incorporated into structural details without affecting the design schedule; the change affected the location of switchyard mirrors.

Integrated Computer Controls System (ICCS). There has been excellent progress in Title II design of the ICCS. The first of the Mid-Title II (65%) reviews, the supervisory software frameworks 65% design review, was completed in June and featured results obtained from the prototype. The review covered the development process, the object-oriented architecture, important CORBA test results, and the simulation program plan. Review documentation featured the first releases of seven (of about 30) software design descriptions to be prepared for the project. The next iteration of the software will incorporate database functionality and advanced error detection and recovery. Comments from the review team are pending. An overview document called the Integrated Computer Control System Architectural Overview (NIF-0002479) was prepared to assist the 65% review team in understanding the model-driven approach used in the ICCS. Sections of the document introduce the layered control system model, NIF software applications, computer and network hardware infrastructure, common object request broker architecture distribution, software development tools and environment, the abstract supervisory software framework, and software deployment. This overview document will be published on the LLNLintranet and updated periodically to incorporate the latest summary information.

Integrated Timing System. The Two-Way Time Transfer Demonstration System has undergone environmental testing and a manufacturer-supplied upgrade while at Jet Propulsion Laboratory. The temperature effects on both transmission path length and terminal equipment were characterized. Upgrades addressing the long-term stability are planned for next quarter. In support of Local Timing Distribution development, measurements were made to characterize commercial delay generators operating in a clock-synchronous trigger mode. Results were excellent, with jitters less than 10 ps RMS and 15-hr stability of 20 ps RMS. The system will be delivered to LLNL in early July for continued development and testing.

Mirror Mounts. Testing continued this quarter to determine the mounting details for switchyard and target area mirrors that need to be supported from the backside. The specifications and cost of designs that are robust enough to withstand the target-backscattered UV light are being investigated.

Optical System Modeling. A detailed optical model (using commercial lens design software) has been completed. The model is wholly consistent with the optical configuration and includes the capability to simulate the alignment system operation. The model allows verification of such things as clear apertures, end-to-end wavefront error, and installation sensitivities.

Laser System Ghost Analysis. A nonsequential ray trace model for the main laser system with spatial filter beam tubes and vessel walls has been constructed. This model was used to calculate the ghost-reflection beam fluences inside the spatial filter beam tubes and to determine the locations of baffles and absorbers. The spatial filter vessel design is very compatible with the stray light management approach.

Final Optics Assembly. An engineering change request was approved in May for the final optics configuration. This changes the focal length of the focus lens from 7 m to 7.7 m, which enables the mechanical design to accommodate a line-replaceable unit (LRU) for a single beamline instead of an entire quad (four beams). This will greatly improve maintenance and cleanliness of the LRU. In addition, a contract for a prototype integrated optics module (IOM) was awarded. The IOM is the LRU for final optics, and includes a vacuum housing, vacuum window mount, and the interface to the beam tube and the water-based thermal control system. Initially this hardware will allow for testing of the pumpdown and evacuation concept as well as the thermal stabilization system. Follow-on testing will include integration of this hardware with the final optics cell and its actuation system.

Target Chamber Review. A portion of the Mid-Title II (65%) Design Review for the target chamber will be held on July 10, 1997. This review covers the design for the aluminum chamber so that it can proceed to fabrication. The 65% review for the remaining portions of the target chamber task (e.g., the first wall and the beam dumps) is scheduled for November 1997.

Target Chamber Procurement. During this period, the target chamber proposals were received from four companies. The proposals were reviewed by a technical evaluation team. Two vendors were selected for negotiations, and a final selection was made. A contract was placed with Pitt-Des Moines, Inc., in early July.

Neutron Spectrometer. An engineering change request for the neutron spectrometer (NS) was accepted by the Level 4 (Engineering) Change Control Board. This request added to the project construction all portions of the NS (cone) that are interior to the

switchyard and target bay area, and that portion of the construction exterior to the building that is needed to not preclude the construction of the external portion of the NS. This was accomplished with no increase in cost and no impact to the schedule. A much simpler design for the interior and exterior portions of the NS was developed and was the driving factor in accomplishing the request.

Data Acquisition System. The layout of cable trays and penetrations in the shield wall and floors for the Data Acquisition System is proceeding. Penetration information for present and future diagnostics has been included in the penetration spread sheets and turned in to the architect/engineers (Parsons). The classification report by Parsons' consultant was reviewed, and comments were returned. Details on the security interface control document are being worked out with the appropriate people at Parsons. A preliminary schedule from the British Atomic Weapons Establishment has been received; they are generating a detailed schedule for the diagnostic manipulator. Work has continued toward finishing the target area portion of the NIF Grounding and Shielding Plan.

Start-Up Activities

Beam Symmetry. An engineering change was proposed by the Start-up team and approved by the Level 4 (Engineering) Change Control Board. It modifies the arrangement of a few beam tubes and mirrors in the switchyards and target area. This will allow maximum flexibility in the use of subsets of laser beams during initial NIF testing and long-term facility operations by users, thus permitting the increase of shot rate on target with beam subsets while maintaining symmetrical irradiation.

Operability Model. A status review of the operability model, a discrete-event simulation model, was held during May. Initial estimates of LRU random failure rates and scheduled maintenance requirements are provided as inputs to the simulation. Using these estimates, preliminary simulation results from the Operability Model address two facility issues: (1) estimation of the operations staff that correlates to the maintenance rates and (2) assessment of shot availability versus staffing. During Title II, the model will incorporate updated information on reliability, availability, and maintainability; updated timeline information; identification of types of people for each task; and more detailed characterization of failures and their impact on the shot cycle.

Operating Procedures. A draft *Procedure for Writing NIF Operating Procedures and Training Documents* has been prepared and is being reviewed by start-up personnel. The document outlines a proposed process for developing written operations procedures and training qualifica-

tion documents for NIF. It includes a description of the approach chosen, a plan for implementation, and estimates of time and resources required. Examples of document templates, titles, and contents are given. Operations personnel at Lawrence Berkeley National Laboratory and Stanford Linear Accelerator Center were consulted during preparation of this draft.

Optics Technology

Optics Vendor Facilitization. The schedule for bidding and negotiating the optics facilitization contracts has been maintained with respect to the NIF schedule. Moore Tool Company was awarded a contract in June for the NIF crystal diamond turning. Negotiations for the fused silica facilitization contract began in June, and are expected to be completed in July. Negotiations for the mirrors, windows, and polarizers flats finishing and lens finishing contracts continued through June, and are expected to be completed in July. Work is continuing on the glass melting facility at Hoya, which is scheduled to be completed in October. Zygo Corp. was awarded the contract for amplifier slab finishing facilitization in May.

KDP Crystals. In the KDP rapid growth program, conditions have been identified in subscale tanks that produce the needed aspect ratio for NIF-size boules. The first test at full size will begin in July, with the results available in August. Rapid-growth KDP crystals grown from ultrapure material and continuous filtration at subscale yielded damage thresholds equivalent to the best Beamlet crystals, and above the NIF requirement. Continuous filtration has been added to a full-size tank; the run is scheduled to be complete in early August.

Optical Fabrication Development. The first of the Beamlet Mule focus lenses was produced in June, and damage tests at full aperture are scheduled for July. The second lens is still on schedule to be delivered in July. Initial damage tests of small, inspection-polished cerium-doped mirror substrates were encouraging. Subscale parts will be coated for damage testing in the first fiscal quarter of 1998. Full-size prototype mirrors from three U.S. sources were laser conditioned to the NIF fluence requirement for the transport mirrors. These mirrors will be installed in Beamlet in August.

Educational Outreach. LLNL signed an agreement with Monroe Community College in Rochester, New York, to begin a certificated optics fabrication program this Fall. This is expected to be a significant benefit to the NIF; it will provide trained workers that are needed in the optics fabrication businesses that supply components to the project.

Upcoming Major Activities

During the fourth quarter of FY 1997, the NIF Project will continue its transition from strictly design to the start of conventional facility site-work, special equipment procurement, and vendor facilitization in optics. Site excavation work will begin in August and will continue for several months. Also, the contracts for the start of building construction will be placed. In special equipment, several Mid-Title II (65%) design reviews will be held, and the contract for the target chamber will be placed, along with a contract for large stainless steel plates for the spatial filters. In optics, the contracts for the amplifier slab fabrication facilitization and for lens and window fabrication will be awarded.

NOVA/BEAMLET/NIF UPDATES JULY-SEPTEMBER 1997

R. Ehrlich/S. Burkhart/S. Kumpan

Nova Operations

Nova Operations performed 239 full system shots, resulting in 246 experiments during this quarter. These experiments supported efforts in ICF, Defense Sciences, university collaborations, Laser Sciences, and Nova facility maintenance. The Nova Operations group continued to transfer manpower to support NIF project efforts and to prepare for reduction from a 2- to a 1.5-shift operation at the beginning of the next quarter. With Nova operating from 6:30 a.m. to 8:30 p.m., Monday through Thursday, we expect to achieve an annualized rate of over 700 experiments.

Plans to reduce the routine optical power limits on Nova were formulated and agreed upon by a group of Nova users and operations management. To reduce the rate of optical damage to optics in the laser chain and the target chamber, we reduced the maximum optical power from 6.75 to 5.5 TW per beamline at the first harmonic starting at the beginning of September. The resulting decrease in damage rate will allow us to continue to operate Nova until the proposed July 1999 shutdown with a budget that is continuing to decrease.

Reducing the optical damage will also help us to comply with the anticipated new Laboratory guidelines for operating systems with vacuum-loaded optics without seriously reducing our shot rate. These new guidelines will decrease the size of allowable damage sites on vacuum-loaded optics. In response, we have increased the rate at which we inspect optics for damage and changed the procedures for which personnel access areas near vacuum-loaded optics on Nova. Gate valves were installed on the cryogenic vacuum pumps on the final spatial filter of each beamline; this increases the efficiency with which we can pump the filters after venting to allow safe access near the vacuum-loaded lenses.

Three weeks of successful Petawatt experiments were conducted during this quarter. In addition to use in experiments related to fast ignitor physics, the Petawatt laser demonstrated success in high-resolution radiography of dense objects ($\rho r \geq 150~g/cm^2$) with photons >1 MeV. The extreme brightness and short duration of the Petawatt pulses offer a tool that may be a new alternative to conventional electron accelerator bremsstrahlung hard x-ray sources. Experiments will continue to determine the maximum achievable photon flux.

The Nova laser facility drew many thousands of visitors during the Laboratory's two-day family open house. Visitors toured through the laser bay, switch-yard, ten-beam target bay, and diagnostics loft during what will likely be the last time that the public will be able to view Nova. The disassembly of the Nova two-beam target bay has been scheduled to start in mid-November, with a target time of early January to turn over the facility to the NIF project.

Beamlet Operations

Beamlet completed a total of 60 system shots during 30 shot days this quarter, completing Phase I of the "Test-Mule" frequency-conversion experiments. These were the first large-aperture frequency-conversion experiments in vacuum using the NIF prototype final optics assembly. In addition to those tests, Beamlet began a series of spatial filter pinhole-closure experiments with a 20-ns square and shaped NIF laser pulse propagated through a final $100-\mu r$ cone-type pinhole. The operations and experimental highlights are as follows:

 Completed installation and alignment of the Test-Mule vacuum vessel within which we test the scientific prototypes and concepts for NIF final optics. The 2-m-diam by 2-m-long vessel,

- including a 1-m-square window, emulates the NIF integrated optics module.
- Completed Test Mule thermal stability measurements demonstrating ±0.1°C and a Test Mule window cooling 1/e time of 120 m.
- Installed the final optics cell (FOC), which contains a KDP doubler crystal and a deuterated KD*P tripling crystal. For the Phase I tests, we continued to use the wedged final focus lens in a separate mount as it was used in previous frequency-conversion campaigns. Subsequent experiments (Phase II) will utilize an unwedged (centered) lens mounted in the FOC.
- Demonstrated performance of the frequency converter with full edge support, which is the NIF baseline design. Conducted most of the 50 shots at 200 ps, plus several at 1 ns with drive irradiances to 5 GW/cm². Reduced efficiency relative to theoretical was similar to FY96 experiments where the dominating influence was crystal nonuniformities. Subsequent tests will utilize new KDP from NIF production boules.
- Performed the first 10 of the Pinhole closure tests with 100-μr and 150-μr spatial filter pinholes. The first experiments were performed up to 3.6 kJ at 20 ns through a 100-μr stainless-steel cone. The purpose for this series was to obtain scaling for pinhole closure between temporally square and shaped pulses.

The Beamlet Test Mule was completed in June, and we successfully pumped it to high vacuum near the end of the month. The first task was to verify the thermal stability because frequency conversion with KDP is quite sensitive to temperature variations. To maintain the Test Mule at a constant temperature, it was painstakingly wrapped in Q3 with a maze of aluminum piping with controlled-temperature water circulation and then wrapped with an insulating blanket. Mule surface and water temperature were shown to maintain well within ± 0.1 °C, the engineering requirement.

The NIF physics prototype FOC and integrated optics module (IOM) were successfully tested under vacuum conditions in the Test Mule. The FOC is designed to hold the doubling and tripling crystals and the final focus lens, although for these tests the lens was mounted external to the cell. The cell resides in the IOM with stepper motors for alignment, and is the first LLNL use of full-edge-supported KDP crystals of this size. This series of experiments required two months during this quarter, much of it associated with diagnostic calibration and reactivation of the focal plane diagnostics (FPD).

Following IOM installation and pumpdown, we quickly found that the IOM stepper motors that control

FOC alignment put a great deal of heat into the FOC, up to +4°C in 48 hours, even though the three motors collectively dissipate no more than 1 W at idle. This is because of the radiative-dominated heat flow to the FOC in vacuum. We performed rod shot rocking curves to verify doubler alignment, then pumped the Test Mule to vacuum for diagnostic calibration. Numerous issues were uncovered during the calibration, as the FPD had not been operated for some time, most notable being contamination on some solgel antireflective coatings, which affected the energy balance. With diagnostic issues resolved, we took 16 shots for 1ω calibration, 23 shots for 2ω calibration and doubling efficiency measurement, and 19 shots for 3ω efficiency measurements. We used KDP and KD*P crystals fabricated for the original Beamlet campaigns in 1996, and measured doubling and tripling efficiencies similar to the previous campaign, efficiency-dominated by known crystal nonuniformities. Future frequency-conversion experiments will test crystals grown for NIF, including fast-growth crystals. Finally, we measured the 3ω focal spot, which was within 15% of meeting the the U.S. DOE's Stockpile Stewardship and Management Program requirements.

During this quarter, we replaced the last of the Beamlet fused quartz spatial filter lenses with fused silica versions, some of which were cut from the original round lenses to square, which nearly doubles their resistance to laser induced fracture. Even these lenses are temporary, as we are fabricating thicker (46-mm vs 35-mm) lenses to replace them in early FY98. Beamlet can now operate with no special fluence/intensity restrictions.

The design and fabrication of the offset mirror tower is proceeding towards installation in FY98 first quarter. The Beamlet FPD was designed to accept a beam from a wedged final focus lens, but the NIF baseline is an untilted lens that requires us to offset the beam in order to test that configuration. The beam will be offset and pointed by 2.2° to maintain the FPD alignment with minimal disruption. Concurrent with this is the testing of high-damage-threshold transport mirrors relevant to NIF mirror development.

The final week in FY97 fourth quarter was spent testing new pinhole concepts for NIF. We inserted a 100- μr cone-style pinhole and propagated square pulses up to 3.9 kJ to measure the onset of pinhole closure. Measurements were made using both a pinhole plasma-detecting interferometer and a gated near-field optical imager to understand the extent and effect of pinhole plasma on the propagated laser beam. These tests will continue into FY98, including experiments with NIF shaped pulses to higher fluences.

National Ignition Facility

Overall progress on the National Ignition Facility (NIF) Project remained satisfactory for the fourth quarter of FY 1997. The major site excavation work was completed nearly on schedule, despite unexpected site conditions, and the contractor was demobilized until needed for the backfilling operations. Awards were made for Conventional Facilities Construction Subcontract Packages 3, 4, and 5 at bids several million dollars less than budgeted. In Special Equipment, five Mid-Title II (65%) Design Reviews were held during the fourth quarter, and two major procurement contracts were awarded, for the target chamber and the spatial filter stainless steel. The optics vendor facilitization contracts for laser glass melting, fused silica, and lens and window fabrication were awarded in the fourth quarter also.

There were no Level 0, 1, 2, 3 milestones due during the fourth quarter. There were 13 Department of Energy/Oakland Office (DOE/OAK) Performance Measurement Milestones due, and all were completed. All 34 DOE/OAK Performance Measurement Milestones due in FY 1997 were also achieved. The FY 1998 DOE/OAK Performance Measurement Milestone plan was submitted to DOE/OAK in late September. It specifies approximately 100 milestones covering all aspects of the NIF Project in FY 1998.

Revision 1 of the *NIF Project Execution Plan* (PEP) was approved at Level 1 and issued to controlled distribution in August. The revision contains the revised baseline cost and schedule plans according to the Level 1 directives of January 1997.

Key assurance activities to support litigation activities and the NIF Construction Safety Program, to initiate the *Final Safety Analysis Report*, to conduct assurance audits (e.g., construction safety, *Preliminary Safety Analysis Report* commitments), to prepare for the DOE-EH Assessment, and to support environmental permits are on schedule.

Site and Conventional Facilities

The Title II design effort on Conventional Facilities peaked during the fourth quarter, with all Construction Subcontract Packages (CSPs) at either 100% Issue For Bid or already awarded, with the exception of CSP-6/10, Target Area Building Shell and Buildout, and CSP-11, Landscaping. Title II design on CSPs 1, 2, 3, 4, and 5 have been offered for bid and contracts awarded. CSP-9, Laser Building Buildout & Central Plant, which is the largest of the NIF construction packages, will be issued for bid in October and awarded in December. CSP-6 and CSP-10 will be bid as one contract (CSP-6/10) in February 1998.

NIF site construction has proceeded with a nominal schedule slippage of two weeks due to unforeseen soil

and site conditions: (1) more soil was hauled off site than planned because it was not suitable for stringent NIF requirements for load-bearing compaction, and (2) dumped capacitors were encountered in the excavation of the NIF building footprint.

Construction Packages. The construction work and project management of prequalified contractors has proven to be reliable and predictable to date, and the NIF continues to base construction success on selecting the best contractors. The site preparation contractor (CSP-1) has completed work and was demobilized. The site excavation contractor (CSP-2) completed the major excavation for the NIF in this quarter and was also demobilized until required for backfilling work. The Target Building Mat and Laser Bay Foundations contractor (CSP-3) is mobilized and working on major, underground concrete structures that will support NIF buildings.

Special Equipment

The Title II design continued in the fourth quarter, with the completion of five Mid-Title II (65%) reviews. Also, major procurements began with the award of contracts for the target chamber and stainless steel for the spatial filters.

Optical Pulse Generation. The optical pulse generation software subsystem design requirements (1.3.1) were revised to reflect the existence of the 1:4 split in the preamplifier beam transport section of the beamline and to update the design code requirements. The performance of the redesigned multipass amplifier cavity in the preamplifier module was validated, including the extraction of a >25-J pulse with temporal distortion, meeting the NIF requirements. Title II design efforts to package this design consistent with the NIF space constraints are in progress.

The ring oscillator prototype has been assembled and initial testing has begun. High losses in components and connections must be identified and corrected in order for the system to demonstrate all requirements.

Amplifier. The Amplifier Module Prototype Laboratory (AMPLAB) prototype facility was activated over the past quarter, including obtaining gain measurements over the full aperture of the 1 × 4 column amplifier. Initial results indicate that the amplifier gain requirement is achievable. Activation of the wavefront measurement system is under way, including the use of a Hartmann sensor and Twyman Green interferometer in place of the CEL-V-provided CILAS interferometer, which is delayed. Initial results indicate that the gas motion in the beam path adds a substantial wavefront error and that "double-pulse" interferometry will be required to distinguish the pump-induced aberration in the slabs from the effects of turbulence in the cavity.

Testing of prototype lamps with doped electrodes on both ends demonstrated substantially reduced sputtering. The flashlamp specification will be modified to require this feature. Blast-shield seal tests accumulated over 7500 full-fluence shots with only minor degradation to the seal and no change in leak rate. This data provides confidence in the proposed approach, which will be tested at full scale in FY 1998.

Pockels Cell. Parts for the 4×1 plasma electrode Pockels cell (PEPC) prototype have nearly all arrived, and assembly is in progress for the cell and the diagnostic system. The prototype plasma pulsers have been assembled and tested and perform as expected. The commercial hardware and software selection process for the PEPC controls is complete. The architecture has changed since Title I from a remote I/O-based design to one that uses centralized front-end processors to house the interface hardware. This will reduce the number of required I/O channels and, ultimately, the cost of the system.

Power Conditioning. Assembly of the prototype capacitor module is nearly complete, with full-power testing scheduled to begin in October. Preliminary tests are in progress, including characterization of switch trigger voltage distribution in the ballast enclosure. A seismic analysis of the capacitor module was completed, which validated the rack design but indicated that changes are required in the design of the floor connection details. Switch testing highlights included a 1431 shot run on a PRIMEX ST-300 switch with a 0.242in. initial gap and a steel housing. This implies that the switch might last nearly two years on the NIF without refurbishment. The Maxwell rotating arc gap switch accumulated over 4000 shots without a misfire, and efforts are under way to determine the relative cost of this potential backup. Testing of development capacitors resumed in late July. Second-version capacitor tests (from all manufacturers that have supplied second versions) have also been completed. The control and monitor system design was completed, and the custom waveform digitizers were fabricated and tested.

Beam Transport System (BTS). Significant detail design progression, several innovative design solutions, and value-engineering efforts marked progress in this quarter. Interface control documents were frozen following the Mid-Title II (65%) review, and drawing production began. The checking process has begun on the first complete detail drawings.

BTS led the integration of a 1-in. rise in the entire laser bay chain from laser mirror (LM)1 to LM4 to provide additional clearance for optics handling. All long-lead material orders for FY 1997 have been placed on time and under budget. Despite an increase of 300 tons over Title I design estimates, steel cost was contained through creative use of alternate lower-cost steel production

methods, without sacrificing quality. A major innovation on the switchyard structure mirror support resulted in a design that now accommodates a potential 1-in. settlement of the building while increasing the stability margin of the mirrors by 30%. Cost estimates for site preparation of the two construction lay-down areas were reduced, and environmental assessments indicated that these areas are suitable for use by BTS. A laser bay crane utilization study was completed recommending an additional bridge crane in each laser bay. An Energy Change Request proposing an additional bridge crane in each laser bay was approved at Level 3 (Project Office). A major optimization study of the amplifier upper support structure resulted in a lower-cost system that is easier to fabricate and maintain.

Integrated Computer Control System (ICCS). Title II design progress is satisfactory. The Mid-Title II (65%) Reviews for work breakdown structure (WBS) 1.5.1 (Computer System) and WBS 1.5.6.1 (Video Distribution System) were completed in a joint session; no major issues were raised by reviewers. The Mid-Title II (65%) Review for WBS 1.5.5 (Automatic Alignment System) was also completed; the review committee's summary report is expected in October. The supervisory application status review milestone was completed via a comprehensive presentation of the NIF shot life cycle. A status review was also held for the Integrated Timing System.

Distributed Control System Simulation.

Preliminary results were obtained from the first of a series of performance and resource utilization simulations: a discrete-event simulation model of the computer system during system start-up. Scenarios of planned activity for system start-up from all software components are being constructed and assembled into a single stream. The scenario comprises the first complete draft of the deployment view that shows how all the ICCS software is distributed onto the computers. Beginning with power-up on the computers, all the steps necessary to initialize ICCS service on all the computers and related services are listed, and the dependencies among them are documented. Measurements will be taken on ICCS prototypes to derive data for validating the evolving simulation. Conclusions from computerized simulation runs will expose potential bottlenecks and allow refinements of interactions among planned software, hardware, and network resources so that the system requirements can be met. The ICCS simulation project status was described during the Computer Systems & Network Mid-Title II (65%) Design Review.

Optomechanical Systems. The prototype spatial filter (SF)4 lens cassette was released for fabrication in early September; a November delivery is projected. This prototype package will be used to verify that the mechanical design meets several of its key design

requirements (e.g., structural stability, cleanliness). Several vacuum seal concepts will be evaluated for ease of assembly, vacuum compatibility, and cleanliness.

Optical Design. The Mid-Title II (65%) review for optical design was presented during three one-half day sessions on July 14–15. Detailed information for main laser design, switchyard and target area transport mirrors, optics specifications, and large optics drawings were presented. Also discussed were the final optics, stray light control, and the injection system and other aspects of the optical pulse generation system.

The optical design model for the Preamplifier Beam Transport System (PABTS) was completed. There are 16 configurations because of the slight variations in path length under the transport spatial filter and in the switchyard. Significant progress was also made in finalizing the multipass amplifier layout in the PAM. Successful experimental results (reported under WBS 1.3.1) led to scientific and engineering consensus on the optomechanical layout and packaging. The optical configuration drawing should be ready for approval in the first quarter of FY 1998.

Detailed tables documenting the analysis of clear apertures and mirror sizes for the switchyard and target area mirror system were transmitted in August to LLNL for review by the optical design, optics manufacturing, and mirror mount design teams. Optical design models for all 192 beam paths have been created, which include 832 mirrors. Determination of final mirror sizes is ongoing based on the results of this analysis.

The optical design of the output sensor was presented at a Mid-Title II (65%) review on September 19; the relay optics system was also reviewed. This design is closely coupled with efforts in System Control (WBS 1.7) to build a prototype output sensor.

Final Optics Assembly. The integrated optics module (IOM) prototype (conventionally machined) was received in September. Also, a fabrication contract was awarded for an IOM manufactured by a casting process, which will be compared to the conventionally machined prototype. Objectives of the prototype testing include the vacuum outgassing characteristics of cast aluminum, suitability of surface finish for cleanliness control, operation of the thermal control system, and manufacturing cost.

The prototype IOM vacuum housing holds the vacuum window and the final optics cell (FOC), which is the precision mount for the harmonic conversion crystals and the focus lens. Objectives of the prototype testing include cleanliness, vacuum pump rates, thermal control system, and manufacturability.

Laser Control. Emphasis is shifting from discussion and evaluation of design options to making decisions for the final design and producing detail drawings. Only a few informal 30% or "status" reviews remain, and the first of the more formal Mid-Title II (65%) reviews was

presented. Some prototype components are being tested, while others are in fabrication. Laboratory space is being prepared for assembly and testing of additional prototype components, and planning has started for eventual handling of production hardware.

An analytical modeling effort of the adaptive optic systems was begun. One goal of the work is to develop better computation models of the principal components in the wavefront correction systems, i.e., the deformable mirror, wavefront sensor, and closed-loop controller. The other main goal is to apply the optimized models to simulations of the entire laser system. This will enable the laser performance to be more accurately predicted and will enhance the ability to identify ways in which existing components can be improved, or additional components can be added, to obtain better overall performance. It has already been established that increasing the number of deformable mirror actuators or adding an appropriate fixed corrector in each beamline will reduce the attainable focused spot size. However, technology and cost constraints are also important considerations that must be evaluated.

Target Experimental Systems. The Title II design effort for the Target Experimental Systems has progressed satisfactorily during the past quarter. A significant accomplishment is the ordering of the aluminum by Pitt-Des Moines Inc. (PDM) for the fabrication of the NIF target chamber. The material will be shipped from the mill directly to France for forming. Forming is scheduled for mid-November.

Operations Special Equipment. Operations Special Equipment successfully completed nine informal reviews of prototyping procurements during this quarter. Several significant pieces of clean-room hardware were delivered and installed in the B432 prototyping clean room. The line-replaceable unit prototype canisters have arrived and are being installed for testing.

Start-up Activities

Integrated Project Schedule (IPS) Management. The IPS database has increased from 1200+ activities to over 9000 activities. The file has significantly more detail than the March 1997 rebaselined IPS. The Integrated Schedule team is in the process of integrating the Project milestones into the appropriate areas of the schedule based upon responsibility. The team also continued to work with Cost Account Plan (CAP) managers to finalize the detailed schedules required to support the CAP planning completion.

Start-up Planning. Recently, start-up planning has focused on the coordination of ICCS planning with start-up planning. A list of development laboratories is being generated for the purpose of ensuring that the computer controls have maximum opportunity for prototype testing of the controls system with actual

NIF hardware. The Optical Pulse Generation Lab and the Laser Alignment Lab plans were reviewed, and in both cases additional opportunities were identified for maximizing readiness for start-up. Another result has been an increased emphasis by the Front-End Processor Working Group to identify common equipment in their designs.

A draft list of operability and maintainability issues has been identified that could be used by operations personnel who are participating in the Title II design teams. Issues include assembly, installation and contamination control, electrical racks and cabling, transport vehicles, temperature stability requirements, and operational support facilities.

Optics Technology

The schedule for bidding and negotiating the optics facilitization contracts has been maintained, with minor slips having little or no impact on the overall NIF schedule. Following negotiations in July, Corning and Tinsley were awarded contracts in September for the fused silica and lens finishing facilities respectively (both were DOE/OAK Performance Measurement Milestones). Proposals for coatings facilities are due in October, with awards expected in the first quarter of FY 1998. Work is continuing on the glass melting facility at Hoya, which is scheduled to be completed in October, and the Schott development run will take place in November.

In potassium dihydrogen phosphate (KDP) rapid growth, significant success has been achieved with the growth of a 55-cm (lateral) crystal. The final 10 cm of growth showed no inclusions, proving out the most problematic part of the process. Additional crystals based on the new aluminum platform design will be grown in the first quarter of FY 1998.

Damage thresholds at 3 ω continue to fall short of expectations for fused silica parts, despite significant advantages achieved in metrology and in finishing technology. While parts can consistently be manufactured to 6 in. in diameter with high-damage thresholds, problems still exist, and damage thresholds for full-size optics are lower than anticipated. Further work, focused on Tinsley Laboratories in Richmond, will be done in the first quarter of FY 1998 at both 6 in. and full scale.

Laser Glass. Raw materials (many tons) were shipped to Germany for powder processing in preparation for the Schott melting campaign. The development run is now scheduled for the first quarter of FY 1998.

KDP Crystals. The KDP Rapid Growth program achieved a major milestone by growing the largest rapidgrowth crystal ever. The crystal was grown on an ultrastiff teflon-coated aluminum platform. It grew to full size, even growing into the vertical support bars without spoiling the crystal or "crashing" the solution. All crystal surfaces were clear of inclusions for the final 10 cm of growth. While the crystal still does not have the internal quality needed for the NIF, the favorable results during the last, and most problematic, part of the growth phase were extremely encouraging. Additional aluminum platforms of large size to accommodate full-size NIF boules are currently being constructed. Analysis of optical absorption dependence on impurity level was completed, which showed that all absorption near the third harmonic is due to iron. This means that for optical performance, work must now be done on controlling the impurity level of a single element.

Color Separation Grating. The first full-scale color separation grating (CSG), which was made back in July, demonstrated a problem when it was coated with a solgel AR. The sol-gel degrades the optical performance by ~4%, causing 3ω light to be diffracted in a similar manner to the 1ω and 2ω light. A second full-scale CSG fabrication has now been completed, and etch depths appear ideal (the first part was off by 20 nm). New solgel coating techniques are being evaluated; the second full-scale part is to be used for the Beamlet Mule campaign in October.

Upcoming Major Activities

During the first quarter of FY 1998, Conventional Facilities construction will officially begin with placement of concrete in October. Also, the architect/engineer, Parsons, will complete all of the Title II design packages for Conventional Facilities. The Notice-to-Proceed for CSP-5 for the Optics Assembly Building will be issued in October. In Special Equipment, six Mid-Title II (65%) Design Reviews and two Title II (100%) Design Reviews will be completed. In Optics, the activities for bidding and negotiating the optics facilitization contracts will continue.

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Woolsey, N. C., Hammel, B. A., Keane, C. J., Asfaw, A., Back, C. A., Moreno, J. C., Nash, J. K., Calisti, A., Mosse, C., Stamm, R., Talin, B., Klein, L., and Lee, R. W., Evolution of Electron Temperature and Electron Density in Indirectly Driven Spherical Implosions, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-JC-125756; Phys Rev. E 56(2), 2314–2317 (1997).

Wyslouzil, B. E., Cheung, J. L., Wilemski, G., and Strey, R., *Small Angle Neutron Scattering from Nanodroplet Aerosols*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-JC-127281; *Phys. Rev. Lett.* **79**(3), 431–434 (1997).

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Yoshiyama, J., Camp, D., Genin, F. Y., Hutcheon, I., Kozlowski, M. R., Salleo, A., Sheehan, L., and Thomas, I., Study of the Effects of Polishing, Etching, Cleaving, and Water Leaching on the Laser-Induced Damage of Fused Silica at 355 nm, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-JC-128362 ABS. Prepared for the Annual Symp on Optical Materials for High Power Lasers, Boulder, CO, Oct 6, 1997.

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Zaitseva, N. P., De Yoreo, J. J., Dehaven, M. R., Vital, R. L., Montgomery, K. E., Richardson, M., and Atherton, L. J., Rapid Growth of Large-Scale (40–55 cm) KH₂PO₄ Crystals, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-JC-125387; J. Crystal Growth **180**(2), 255–262 (1997).

1997 ICF Awards, Patents, and Refereed Publications

The 1997 ICF Annual Report uses this space to report on the Awards received by, Patents issued to, and Publications by LLNL employees in the ICF Program. The goal is to showcase the distinguished scientific and technical achievements of our employees.

The *Annual Report* is based on the Fiscal Year of 1997, whereas the achievements listed here are based on the Calendar Year of 1997. The reason for this disparity is the fact that a publication or award may not have a precise date other than the particular year it was given.

The awards listed are those granted by recognized organizations outside of LLNL and given to ICF Program employees.

The patents may include work that is afield from ICF but are granted to ICF Program employees. This could include work that is supported from discretionary funds.

The publications listed are those from refereed scientific journals. Therefore, conference proceedings are generally not included unless they are also published in refereed scientific journals. The work in ICF is broad-based at LLNL, and many employees who are not directly in the ICF Program publish ICF-related results; these publications are included. Furthermore, publications are included in which an ICF Program author contributes but is not the lead author.

1997 ICF Program Awards

R&D 100 Awards

Absolute Interferometer—Gary Sommargren, Eugene Campbell, Don Phillion, Frank Snell

Ultra Clean Ion Beam Sputter Deposition System—Don Kania, Patrick Kearney, Richard Levesque, Steve Vernon

Femtosecond Laser Materials Processing—Brent Stuart, Michael Perry, Hoang Nguyen, Steve Herman, Paul Armstrong, Paul Banks, Michael Feit, Alexander Rubenchik, Booth Myers, Howard Powell, Joseph Sefcik

Federal Laboratory Consortium Awards

A Stroke Treatment System to Emulsify Blood-Clots and Quickly Restore Blood Flow Following a Stroke, Based on Fiber-Optic-Delivered, Opto-Acoustic Thrombolysis—Peter Celliers, Luiz Da Silva, Dennis Matthews, Richard London, Duncan Maitland, William Benett, Peter Krulevitch, Abraham Lee, Patrick Fitch

Ultra-Clean Ion Beam Sputter System (IBD-350)—Don Kania, Patrick Kearney, Richard Levesque, Swie-In Tan

Edward Teller Medal Awards

Michael H. Key

George Zimmerman

American Physical Society Fellows

Max Tabak

Charles Verdon

Industry Week's 5th Annual Technology & Innovation Awards "50 R&D Stars to Watch"

Thomas E. McEwan

Northern California Society for Technical Communication Competition

Award of Distinguished Technical Communication

Experimental Interstage Processing Furnace—Mark McDaniel, Tom McCarville

National Ignition Facility—Sandy Lynn, Scott Dougherty, Jason Carpenter

Nova Laser Facility—Sandy Lynn, Scott Dougherty, Jason Carpenter

Award of Excellence

ICF Quarterly Report 96-2—Jason Carpenter, Al Miguel, Pam Davis, Sandy Lynn, Don Correll, Roy Johnson, Deanna Pennington

Award of Merit

ICF Quarterly Report 96-3—Jason Carpenter, Al Miguel, Sandy Lynn, Don Correll, Roy Johnson Global Precision Optical Weapon—Mark McDaniel, Victor George Science and Engineering Fair—Scott Dougherty, Karen Kiernan

Award of Achievement

High Temperature Plasma Diagnostics—Sandy Lynn, Joe Kilkenny
Plasmas for National Security—Sandy Lynn, Don Correll
Document Services—Jason Carpenter, Mark McDaniel, Barbara Zears

International Society for Technical Communication Competition

Nova Laser Facility—Sandy Lynn, Scott Dougherty, Jason Carpenter

1997 ICF Patents

John S. Taylor Precision Non-Contact Polishing Tool U. S. Patent 5,591,068 January 7, 1997.

George D. Craig, Robert Glass, and Bernhard Rupp

System and Method for Forming Synthetic Protein Crystals to Determine the Conformational Structure by Crystallography U. S. Patent 5,597,457 January 28, 1997.

Thomas E. McEwan *Electronic Multi-Purpose Material Level Sensor* U. S. Patent 5,609,059 March 11, 1997.

William J. Benett, Peter A. Krulevitch, Abraham P. Lee, Milton A. Northrup, James A. Folta

Miniature Plastic Gripper and Fabrication Method

U. S. Patent 5,609,608

March 11, 1997.

Thomas E. McEwan High Accuracy Electronic Material Level Sensor U. S. Patent 5,610,611 March 11, 1997.

Lloyd A. Hackel and Patrick Reichert *Faraday Imaging at High Temperatures* U. S. Patent 5,612,538 March 18, 1997.

Raymond J. Beach, William J. Benett, and Steven T. Mills *Fiber Optic Coupling of a Microlens Conditioned, Stacked Semiconductor Laser Diode Array* U. S. Patent 5,617,492 April 1, 1997.

Thomas E. McEwan

Micropower RF Transponder with Superregenerative Receiver and RF Receiver with Sampling Mixer U. S. Patent 5,630,216 May 13,1997.

James A. Folta
Miniaturized Flow Injection Analysis System
U. S. Patent 5,644,395
July 1, 1997.

Milton A. Northrup, Dino R. Ciarlo, Abraham P. Lee, Peter A. Krulevitch *Microfabricated Therapeutic Actuator Mechanisms* U. S. Patent 5,645,564 July 8, 1997.

Jerald A. Britten

Moving Zone Marangoni Drying of Wet Objects Using Naturally Evaporated Solvent Vapor U. S. Patent 5,660,642 August 26, 1997.

Thomas E. McEwan Window-Closing Safety System U. S. Patent 5,661,385 August 26, 1997.

Thomas E. McEwan

Time-of-Flight Radio Location System
U. S. Patent 5,661,490

August 26, 1997.

Stephen A. Payne and Joseph S. Hayden *Ultrafast Pulsed Laser Utilizing Broad Bandwidth Laser Glass* U. S. Patent 5,663,972 September 2, 1997.

Kathleen I. Schaffers, Laura D. DeLoach, Stephen A. Payne, and Douglas A. Keszler *Ytterbium-Doped Borate Fluoride Laser Crystals and Lasers* U. S. Patent 5,677,921 October 14, 1997.

Thomas E. McEwan *Pulse Homodyne Field Disturbance Sensor* U. S. Patent 5,682,164 October 28, 1997.

C. Brent Dane and Lloyd A. Hackel Long-Pulse-Width, Narrow Bandwidth Solid State Laser U. S. Patent 5,689,363 November 18, 1997.

Raymond J. Beach

High Efficiency 2 Micrometer Laser Utilizing Wing-Pumped Tm³⁺ and a Laser Diode Array End-Pumping Architecture U. S. Patent 5,689,522 November 18, 1997.

Natale M. Ceglio and David A. Markle *Maskless, Reticle-Free Lithography* U. S. Patent 5,691,541 November 25, 1997.

Ralph H. Page, Kathleen I. Schaffers, Stephen A. Payne, William F. Krupke, Raymond J. Beach Optical Amplifier Operating at 1.3 Micron Useful for Telecommunications and Based on Dysprosium-Doped Metal Chloride Host Materials
U. S. Patent 5,694,500
December 2, 1997.

Sherry L. Baker, Stephen P. Vernon, Daniel G. Stearns *Recovery of Mo/Si Multilayer Coated Optical Substrates* U. S. Patent 5,698,113 December 16, 1997.

1997 ICF Program Refereed Publications

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- B. B. Afeyan and E. A. Williams, "A Variational Approach to Parametric Instabilities in Inhomogeneous Plasmas I: Two Model Problems," *Phys. Plasmas* **4**(11), 3788–3802 (1997).
- B. B. Afeyan and E. A. Williams, "A Variational Approach to Parametric Instabilities in Inhomogeneous Plasmas II: Stimulated Raman Scattering," *Phys. Plasmas* **4**(11), 3803–3826 (1997).
- B. B. Afeyan and E. A. Williams, "A Variational Approach to Parametric Instabilities in Inhomogeneous Plasmas III: Two-Plasmon Decay," *Phys. Plasmas* **4**(11), 3827–3844 (1997).
- B. B. Afeyan and E. A. Williams, "A Variational Approach to Parametric Instabilities in Inhomogeneous Plasmas IV: The Mixed Polarization High-Frequency Instability," *Phys. Plasmas* **4**(11), 3845–3862 (1997).
- P. Amendt, S. G. Glendinning, B. A. Hammel, O. L. Landen, T. J. Murphy, L. J. Suter, S. Hatchett, M. D. Rosen, S. Lafitte, D. Desenne, and J. P. Jaduad, "New Methods for Diagnosing and Controlling Hohlraum Drive Asymmetry on Nova," *Phys. Plasmas* **4**(5), 1862–1871 (1997).
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